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ISSUE 141
APRIL 2023

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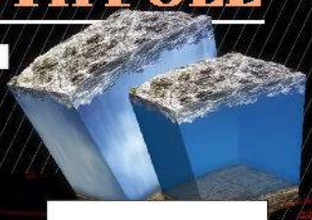

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"FINDING LIFE ELSEWHERE IS ABSOLUTELY CRITICAL"

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WELCOME

ISSUE 141

SCAN HERE TO GET OUR DAILY NEWSLETTER

Join us as we reveal more about time. This month, researchers are puzzling as to whether the 'fourth dimension' is really an illusion – discover what physicist Sean Carroll and his team have discovered in our cover feature, and find out how time differs depending on where you are in the cosmos.

This issue, we also reveal how you can increase your knowledge of the universe – and have information at your fingertips – with **All About Space**'s pick of the very best space apps. And if you're looking for more recommendations for observing equipment, kit, accessories and gifts, then our experts have plenty to show you in our review and 'in the shops' sections. Speaking of gifts, if you're looking for present ideas for a loved one or even for yourself, we have an exclusive special offer for our readers: whether this is your first issue or one of many. I've signposted it to the right of this page.

As ever, we love meeting our readers, so please do drop us a line on Twitter, Facebook or via email. I look forward to hearing from you.

GEMMA LAVENDER
Editor

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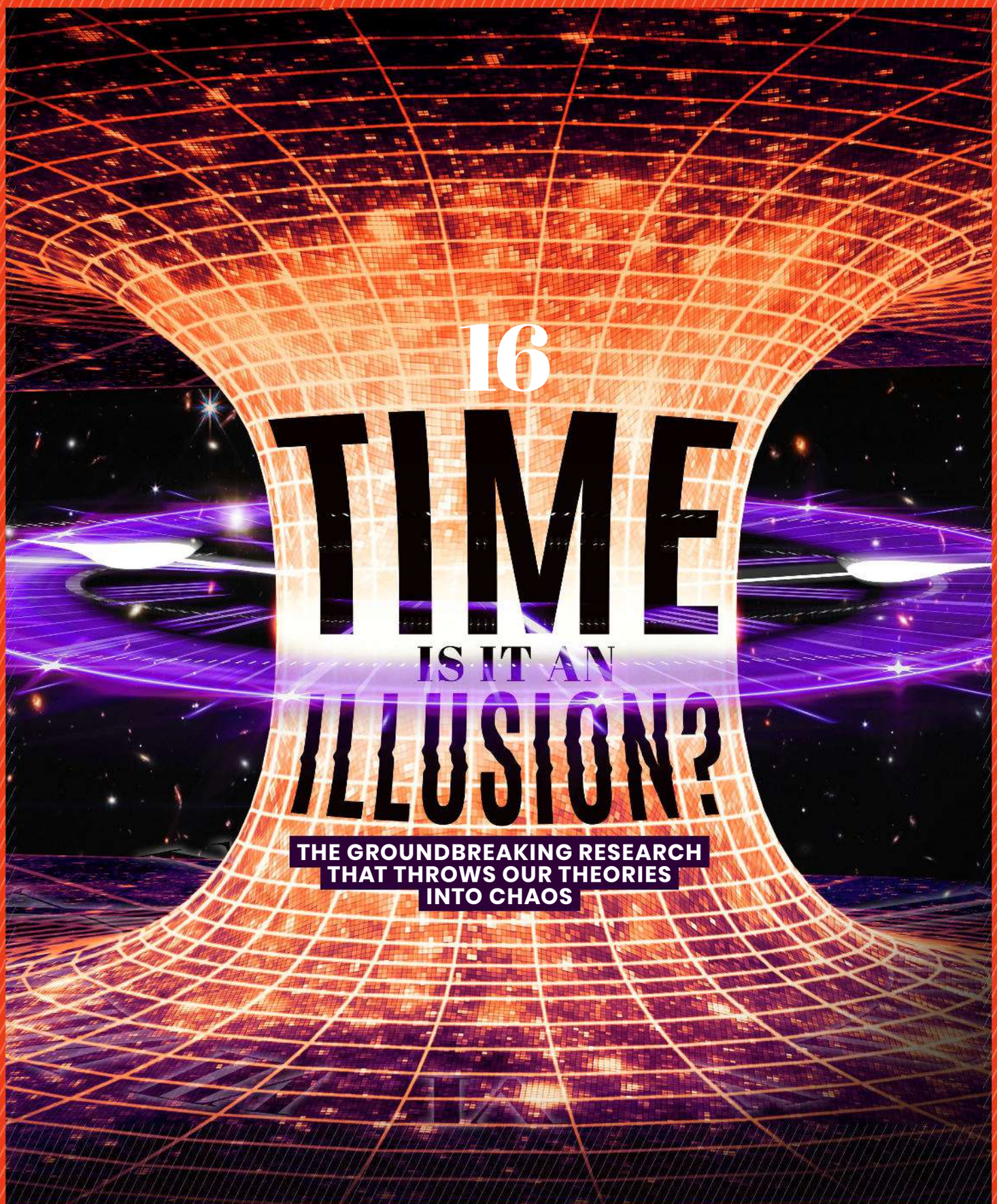

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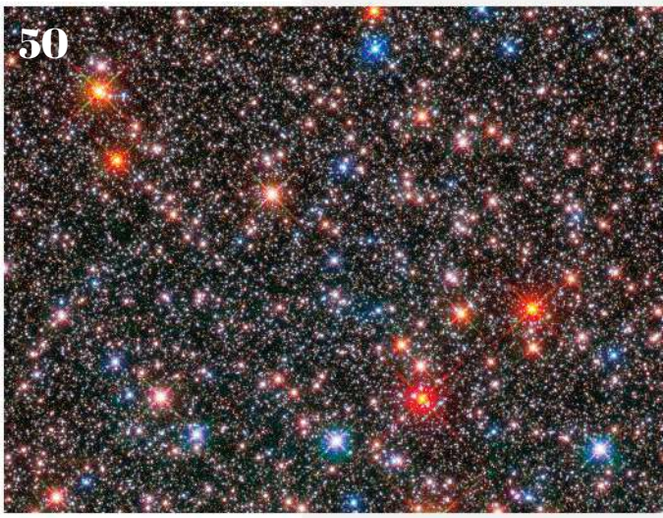

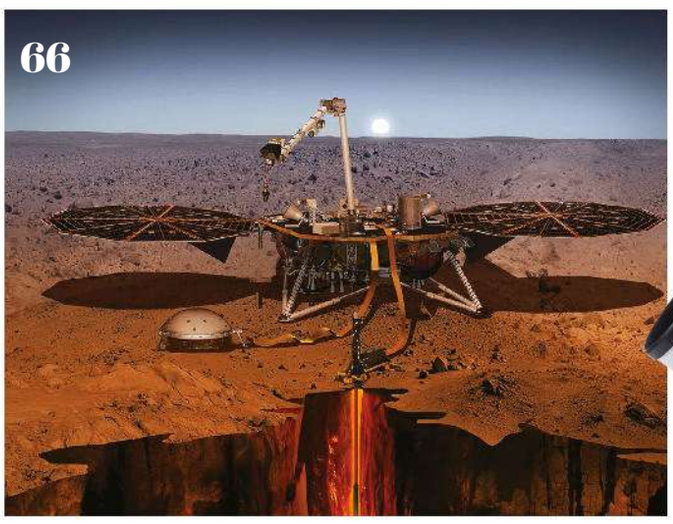

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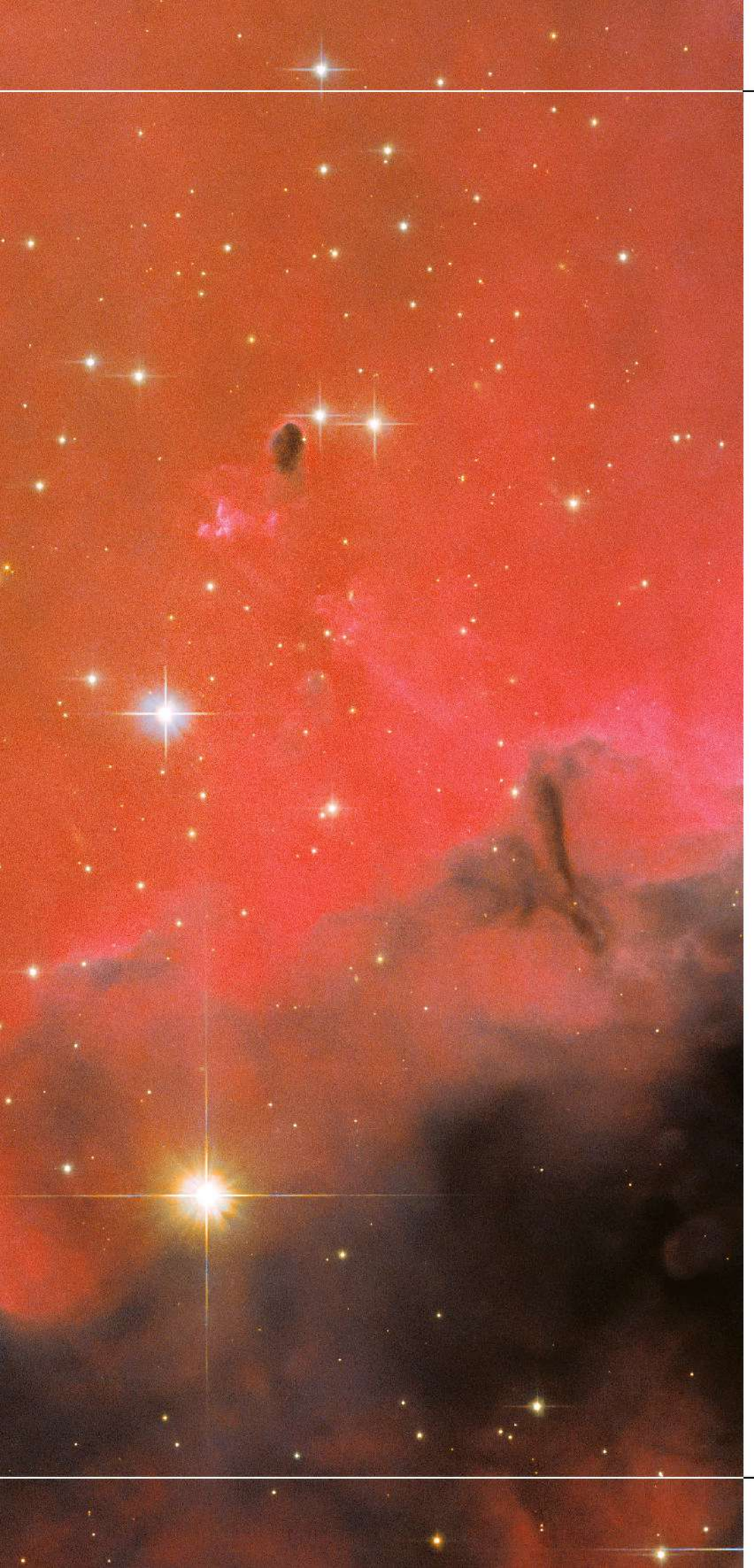


19 December 2022

Red view of the Soul Nebula

The Hubble Space Telescope captured a stunning image of a small region of Westerhout 5, also known as the Soul Nebula, glowing red. The suffusion of red light is caused by H-alpha emission, which happens when very energetic electrons within hydrogen atoms lose energy, causing the release of this distinctive red light. This red light also reveals a range of fascinating features, such as a so-called free-floating evaporating gaseous globule (frEGG). Seen as a dark, tadpole-shaped region in the upper centre of the image, this frEGG is officially named KAG2008 globule 13 or J025838.6+604259.

This and other frEGGs belong to a special class of evaporating gaseous globules (EGGs) that occur in nebulae when energetic radiation from young, hot stars ionises surrounding gas by stripping away electrons. This causes the gas to disperse away from those bright stars in a process called photoevaporation, which may help halt star formation in nebulae.

In EGGs, the gas is so dense that this photoevaporation process happens much more slowly than it does in the surrounding regions of gas, allowing gas to remain dense enough to collapse and form protostars, which eventually go on to become full-fledged stars. Astronomers are interested in frEGGs and EGGs because they are areas of nebulae where star birth may have once taken place.

The Soul Nebula is the partner of another nebula: the Heart Nebula. Officially known as IC 1805, the massive cloud of gas and dust is so named because the glowing hydrogen content makes it resemble a pink heart.

© ESA/Hubble; NASA, R. Sahai

23 January 2023

Webb uncovers an icier side to space

The James Webb Space Telescope has peered deep into a dense molecular cloud and found a rich variety of pristine interstellar ice, including a range of molecules crucial for life. Spotted at frigid temperatures of -263 degrees Celsius (-440 degrees Fahrenheit), these finds are the coldest ices ever measured. “We simply couldn’t have observed these ices without Webb,” Klaus Pontoppidan, an astronomer at the Space Telescope Science Institute said. Webb studied a neighbourhood that scientists call Chameleon I in the constellation of Chameleon.
500 light years away from Earth, it’s one of the closest star-forming regions, with dozens of pockets alive with young stars. The region belongs to a family of what astronomers long thought to be holes in the sky: dark molecular clouds so dense with gas and dust that visible light from background stars fails to penetrate them. Clouds like Chameleon I are stellar nurseries; their collapse over time forms stars. The chemical composition of these systems and any building blocks of life they may contain, however, is determined by the ices embedded deep inside the molecular cloud.

With Webb’s powerful instruments, including its near-infrared camera (NIRCam), astronomers have probed into Chameleon I’s dusty heart and discovered ices at their early stages of evolution – just before the cloud’s core collapses to form protostars. The team used light from two background stars, NIR38 and J110621, to light up Chameleon I in infrared wavelengths. The cloud’s different molecules that are locked in ices absorb starlight in different infrared wavelengths. Astronomers then studied the chemical fingerprints that showed up as dips in the resulting spectral data. This data helped the team identify how much of which molecules are present in Chameleon I.

© NASA; ESA; CSA

18 January 2023

Gargantuan survey of the Milky Way

An ambitious new survey of the Milky Way's galactic plane has revealed 3.32 billion cosmic objects in stunning detail. The enormous celestial catalogue, possibly the largest of its type, was built using data from the Dark Energy Camera at the Cerro Tololo Inter-American Observatory in Chile, which is operated by the National Science Foundation (NSF). "Imagine a group photo of over 3 billion people and every single individual is recognisable," Debra Fischer, division director of astronomical sciences at the NSF, said. "Astronomers will be poring over this detailed portrait of more than 3 billion stars in the Milky Way for decades to come."

Our Milky Way is populated by hundreds of billions of stars, huge numbers of star-birthing regions and massive clouds of gas and dust. Cataloguing such objects is a massive task, but the team behind the new catalogue – the second data release from the Dark Energy Camera Plane Survey, known as DECaPS2 – was up to the challenge. Researchers used the Dark Energy Camera to observe the plane of the Milky Way at optical and near-infrared wavelengths, revealing this region of our galaxy in unprecedented detail. The catalogue took two years to complete, with the Dark Energy Camera producing over ten terabytes of data from 21,400 individual exposures.

"One of the main reasons for the success of DECaPS2 is that we simply pointed at a region with an extraordinarily high density of stars and were careful about identifying sources that appear nearly on top of each other," said Andrew Saydjari, a graduate student at Harvard University and a researcher at the Harvard-Smithsonian Center for Astrophysics. "Doing so allowed us to produce the largest such catalogue ever from a single camera in terms of the number of objects observed."

© DECaPS2; DOE; FNAL; DECam; CTIO; NOIRLab; NSF; AURA

An artist's impression of Jupiter's Great Red Spot and its moon Io

New aurorae detected on Jupiter's four largest moons

Reported by Robert Lea

Astronomers have discovered new aurorae over Jupiter's four largest moons – Io, Europa, Ganymede and Callisto – observable at visible wavelengths. These reveal the compositions of the thin atmospheres of the Jovian moons in greater detail, including traces of oxygen and sodium, but only minimal water vapour. A team made the discovery while observing the moons as they sat in the shadow of Jupiter using the Keck Observatory's High-Resolution Echelle Spectrometer (HIRES), as well as high-resolution spectrographs at the Large Binocular Telescope and Apache Point observatories.

The use of Jupiter's shadow as a sunshade allowed scientists to see the faint aurorae, caused by Jupiter's powerful magnetic field, without them being overwhelmed by bright sunlight reflected from the surface of the moons. "These observations are tricky because in Jupiter's shadow, the moons are nearly invisible," California Institute of Technology professor Katherine de Kleer said. "The light emitted by their faint aurorae is the only confirmation that we've even pointed the telescope at the right place."

The four all possess oxygen aurorae – the same as can be seen in the sky over Earth around our planet's poles. Yet because gases on the Jovian moons are much thinner than on Earth, these aurorae glow in deep red rather than the familiar green glow seen over Earth. On the moons Europa and Ganymede, the Solar System's largest moon, oxygen aurorae are also visible in infrared wavelengths, just outside the red end of the electromagnetic spectrum, and thus can't be seen with the human eye. This is the first time this particular phenomenon has been seen in the atmosphere of a celestial body other than our own planet.

The aurora of Io is striped with a wide range of colours, likely arising from the fact that this Jovian moon is considered the most volcanically active body in the Solar System. As a result of this violent volcanism, plumes of gas and dust are launched from Io's surface. These plumes contain salts like sodium chloride and potassium chloride, which break down to produce additional colours in Io's aurorae. The range of colours includes a yellow-orange glow that comes from sodium and an infrared aurora caused by potassium which has never been detected anywhere else. "The brightness of the different colours of aurorae tell us what these moons' atmospheres are likely made up of," de Kleer said. "We find that molecular oxygen, just like what we breathe here on Earth, is likely the main constituent of the icy moon atmospheres."

The observations revealed only minimal traces of water vapour, a result that may impact the ongoing debate of whether the atmospheres of the Jovian moons are rich with water molecules. Jupiter's magnetic field is titled, meaning that the brightness of the aurorae of the Galilean moons changes as the gas giant rotates.

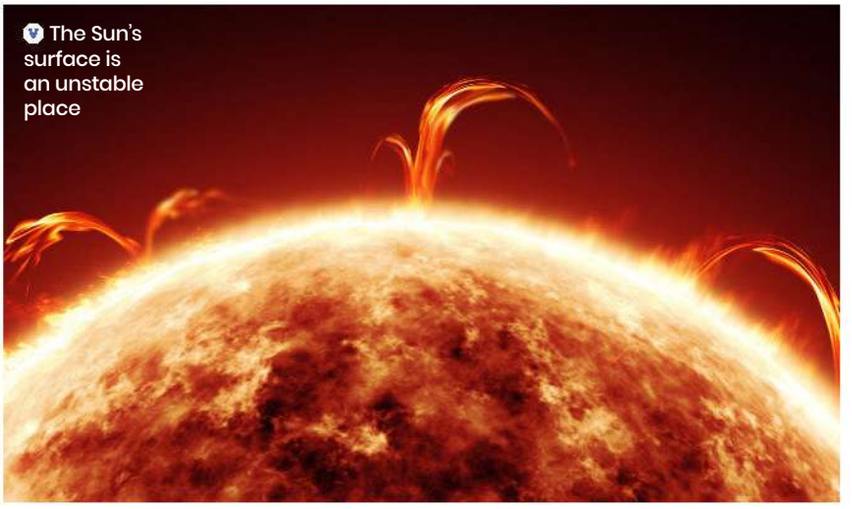
Physicists mimic the gravity inside the Sun using sound waves

Reported by Tariq Malik

Physicists have replicated the kind of gravitational field found in or near the Sun using sound waves inside a sphere of hot plasma, creating a field analogous to gravity that's able to overcome the effect of Earth's gravity that can drag such experiments down. The Sun's visible surface, or photosphere, is a roiling, turbulent sea of convective plasma. Plasma is ionised gas in which the atoms have been shorn of an electron, giving them an electrical charge. Hot plasma rises from deeper within the Sun to the photosphere, with cooler plasma sinking back down, where it's reheated and recycled back to the photosphere. This convective motion is radial, outward from the centre of the Sun, but trying to replicate radial plasma fields on Earth faces one big problem: our planet's gravity, which drags down towards Earth rather than to the centre of the plasma field in a laboratory experiment.

Because so much of our understanding of space weather begins with understanding the behaviour of plasma and magnetic fields on the photosphere, it's important to have a clear insight into those radial convective processes. In the past, scientists resorted to sending experiments into space on board the Space Shuttle to get away from Earth's interfering gravity. Now, physicists led by John Koulakis of the University of California, Los Angeles, have circumvented Earth's gravity by creating a radial force analogous to gravity inside the Sun using sound waves. "Sound fields act like gravity, at least when it comes to driving convection in gas," said Koulakis. The team filled a rotating glass sphere three centimetres (1.2 inches) across with a plasma of sulphur atoms. Microwaves were then employed to heat the plasma to 2,760 degrees Celsius (5,000 degrees Fahrenheit) and generate spherically symmetric acoustic waves that exerted a radial force on the plasma analogous to the gravity on the Sun, with the strongest 'gravity' at the centre of the sphere. "With the use of microwave-generated sound in a spherical flask of hot plasma, we achieved a 'gravity field' that's 1,000 times stronger than Earth's gravity," said Koulakis.

Applying sound to create this effective gravity caused the hot plasma to move from the centre radially outward to the inner surface of the glass sphere, triggering a 'convective instability' that replicates the convective plasma currents that on the Sun transport hot plasma to the photosphere and prompt cooler plasma to sink. The sound waves exert a different pressure on the plasma depending on the plasma's temperature, drawing cooler plasma to the centre of the sphere, where it grows warmer and rises again.



The Sun's surface is an unstable place

Artwork of Ingenuity in flight above Mars

Ingenuity aces its 43rd Mars flight – its longest in ten months

Reported by Mike Wall

NASA's Ingenuity helicopter flew yet again on 16 February, covering more Red Planet ground than it had on a single sortie in nearly a year. The flight was the 43rd overall for the 1.8-kilogram Ingenuity, which landed on the floor of Mars' Jezero crater with the Perseverance rover in February 2021. This latest hop covered 390 metres (1,280 feet) of Red Planet ground, according to Ingenuity's flight log. Ingenuity hadn't flown that far since 29 April 2022, when it travelled 418 metres (1,371 feet) across Jezero's floor.

Ingenuity's longest-ever flight occurred three weeks earlier on 8 April 2022, when the little robot put 710 metres (2,310 feet) on its odometer. During its 43 Mars flights to date, Ingenuity has covered a total of nearly 8.9 kilometres (5.5 miles). That's quite impressive for a technology demonstration that was supposed to fly just five times on the Red Planet.

Ingenuity long ago transitioned out of that original mission. The rotorcraft is now serving as a scout for Perseverance, which is searching for signs of past Mars life and collecting and caching dozens of samples for future return to Earth by another mission. Jezero is a great place to do such work: the 45-kilometre (28-mile) wide crater hosted a big lake and a river delta billions of years ago.

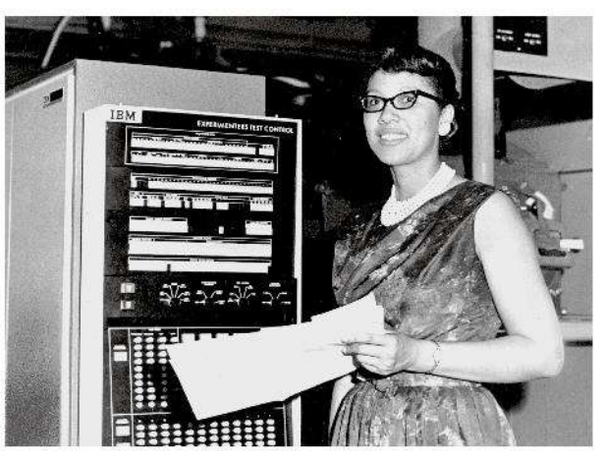
Perseverance recently finished setting up a backup sample cache in a patch of Jezero that the rover team calls Three Forks. The ten tubes in the Three Forks depot will be collected by Ingenuity-like helicopters later this decade if Perseverance isn't healthy enough to deliver its onboard samples to a rocket-toting lander itself. That rocket will blast the samples to Mars orbit, where a spacecraft will snag them and haul them back to Earth, perhaps as early as 2033 – a sample-return campaign that NASA will undertake with the European Space Agency. Perseverance is now beginning to climb up Jezero's ancient delta formation to explore this different and intriguing environment. The rover has put (9.05 miles) on its odometer since touching down.

NASA names a Moon mountain after Black mathematician and 'hidden figure'

Reported by Elizabeth Howell

NASA named a huge Moon landmark after a prominent Black mathematician who worked at the agency during the 'hidden figures' era. The name of Melba Mouton will be designated by NASA on a Delaware-sized flat Moon mountain near the water-rich lunar south pole. The Moon's south pole is a target of Artemis program astronauts, who are expected to land as soon as 2025. The mountain is one of 13 candidate landing sites for Artemis III, and is adjacent to where the agency's ice-hunting Volatiles Investigating Polar Exploration Rover (VIPER) will touch down in 2024 or so. It was the VIPER team who proposed Mons Mouton's name.

Mons Mouton has been proposed to the International Astronomical Union, the official designator of space landmarks. Mouton "charted a path for other women and people of colour to pursue careers and lead cutting-edge science at NASA," Sandra Connelly, the agency's acting associate administrator for science, said. Mouton joined NASA in 1959 at the Goddard Space Flight Center near Baltimore. Shortly after Mouton joined NASA, she became the head mathematician of the 'human computers' who tracked the early communications satellites Echo 1 and Echo 2, which reached Earth's orbit in 1960 and 1964. Mouton then progressed to head programmer in 1961, leading a team responsible for tracking spacecraft locations and trajectories.



Black NASA mathematician Melba Mouton, who worked at the agency between 1959 and 1973

© Getty Images

WIN

A MEADE LIGHTBRIDGE MINI 130 WORTH £250!

Suitable for all ages of any experience, this grab-and-go Dobsonian is perfect for revealing a host of magnificent celestial sights

This Dobsonian is just short of a metre (three feet) in height, but as the old saying goes, good things come in small packages. That's definitely the case with the Meade LightBridge Mini 130. With an aperture of 130 millimetres (five inches), it's more than capable of zooming in on planets, bright deep-sky targets and stars with its exquisite and beautifully crafted light-collecting optics. The telescope tube sits on a swivel base with horizon and vertical movement – a favourite with amateur astronomers due to its simplicity, boasting ease of navigation that makes slewing from one target to the next a breeze. The telescope is supplied with a red-dot finder, a 2x Barlow lens plus two eyepieces – a 9mm and 25mm, which supply magnifications of 72x and 25x respectively. It's the perfect companion for observing a wide selection of astronomical targets.

To be in with a chance of winning, answer this question:

Which of the following isn't a star cluster?

A: Beehive

B: Owl

C: Mouse

Competition ends on 20 April 2023

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TIME
IS IT AN ILLUSION?

TIME IS ONE OF THE MOST PUZZLING PHENOMENA IN THE UNIVERSE. HERE WE TAKE A LOOK AT THE LATEST IDEAS ABOUT ITS NATURE AND ORIGINS

Reported by Giles Sparrow

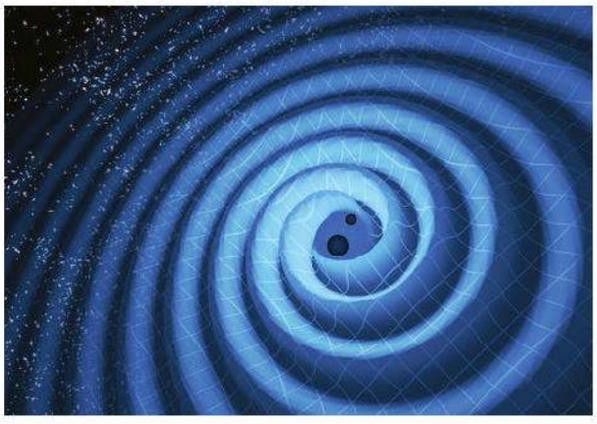
Time's endless flow shapes the way we understand the world. Being carried along on a river of time that only flows in one direction is essential to our understanding of the universe. But what exactly is time, and where does it come from? Recent research is suggesting some surprising new ideas. For more than a century, scientists have treated time as a dimension – a 'direction of travel' both similar to and radically different from the three space dimensions. Thanks to Einstein's theory of general relativity, it's also clear that space and time are wrapped up together in a complex 'continuum' called space-time. In extreme situations, distance in space and the flow of time can be stretched, compressed or even exchanged.

Professor Sean Carroll, author of *From Eternity to Here: The Quest for the Ultimate Theory of Time*, argues that time isn't really that hard to understand. "I don't think it's a mystery, and I don't think it's been a mystery for a very long time," he explains. "It was a bit simpler back when we had Isaac Newton and time and space were both absolute. Then we would have considered the universe to be made of space and everything in it, and the universe keeps happening over and over again – time is just the label we put on those different versions that happen one after another with things in different positions, a bit like the pages of a book.

"In Einstein's view there's actually 'space-time', and how an observer slices that space-time into time and space is a little arbitrary," continues Carroll, the Homewood professor of natural philosophy at Johns Hopkins University. "Different people can look at it in different ways, and no one is right and no one is wrong. But still, in any one point of view there's a sequence of moments. It's a little more complicated, but really it's not that hard – it's certainly no more profound to ask what time is than to ask than what space is."

The effects described by Einstein arise in part because the universe has an ultimate speed limit – the speed of light itself. This means your experience of the present incorporates light and other information that began its journey from distant objects as they were in the past. What's more, everyone's experience of a single moment in time will be different depending on their position and motion in space. The limited speed of light also helps to define cause and effect – a key aspect of our understanding of the universe in which earlier events can shape later ones, but not the other way around. Because one object or event can only influence another if an signal of some kind passes between them, there are limits to the region of past space capable of influencing a particular point in the present. Physicists often depict this idea in terms of a 'light cone', with a single point in present-day space at the tip and an expanding cone reaching back into the past, encompassing regions of space-time capable of influencing that point in the present. There may be plenty more of the universe outside of that light cone, but those regions are forever out of sight and incapable of influence.

"Everyone's experience of a single moment in time will be different depending on their position and motion in space"



But what exactly do we mean by 'earlier' and 'later'? The idea that we're on a one-way journey from the past to the future is another essential part of our understanding of time. "The past and future are different for us in a way that's not true for space," explains Carroll. "All directions in space are the same, but in time the two directions are very different, and there's just one direction that we go in." This experience is usually known as the arrow of time, and most agree

Physicists are using the principles of holograms to try to understand how time works

Collisions between black holes produce gravitational waves – these ripples may reveal 'new' time being created

© Getty; LIGO

WHAT DON'T WE GET ABOUT TIME?

Cosmologists think they have a pretty good understanding of time as a dimension, but there are still questions about the ways in which we experience time

1 Why can't we move backwards in time?

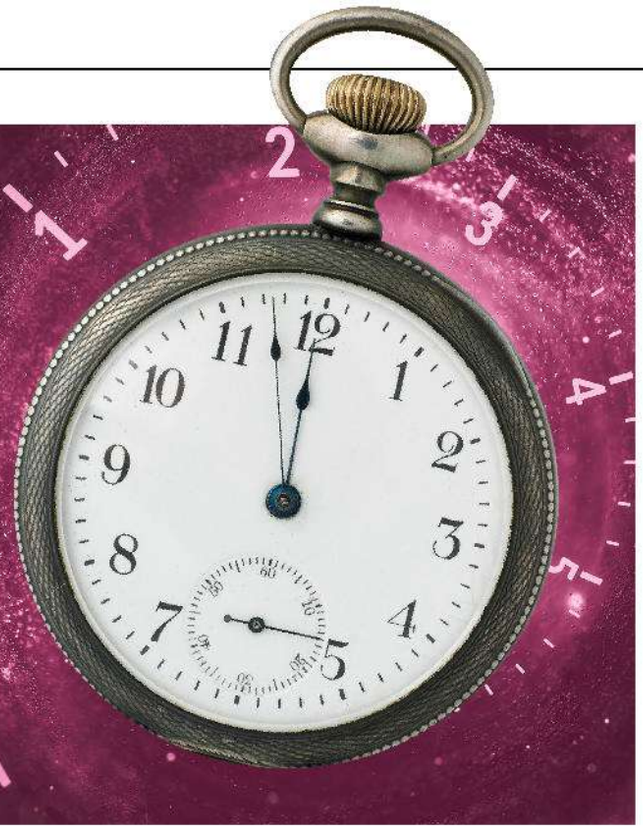
In theory, general relativity permits movement along 'closed timeline curves' that could take a person back in time. But why is it that in practice the equations never seem to work out?

2 Do we really have free will?

Do we really have the ability to make unfettered choices about future events or are we simply following a predetermined course without being aware of it?

3 Why don't we remember the future?

Some physicists think that our ability to form memories is linked to an increase of entropy in our brains, but there's still no comprehensive theory for how this could work.



that it's routed in a concept known as entropy and the laws of thermodynamics which control the behaviour of heat and energy in the universe. Thermodynamics was developed in the 18th and 19th centuries as scientists and engineers attempted to understand the underlying principles of steam engines and other aspects of the Industrial Revolution. Its second law says that in any closed system, the amount of energy available to do useful work of any kind inevitably decreases over time as the amount of entropy increases.

Entropy describes the amount of disorder in any system, including the universe. Put a cup of freshly made tea in a sealed box and leave it for long enough, and this relatively orderly low-entropy arrangement will become more disordered as heat from the tea warms the air in the box and the container itself until eventually everything is uniformly tepid. The tendency of entropy to increase means the tepid tea could never spontaneously extract energy from the warm air to heat itself back up.

Entropy matters because the universe itself is a closed system – while you could pop the tea in a microwave to heat it back up by supplying external energy, there's no way of supplying more energy to the universe. Over trillions of years the universe will inevitably run down to its 'heat death' – a state where the last stars are exhausted and their elements are scattered across space as slowly cooling gas and burnt-out stellar remnants. This effect, according to most scientists, is what defines the direction of time. "In my perspective, the arrow of time just comes from the fact that the entropy of the universe was smaller in earlier times and grows larger at later times," says Carroll. "There's nothing propelling the universe forward in time, it's just you have all these different moments distinguished by the rule that earlier means lower entropy, later means higher entropy. That explains why you can remember the past and not the future, why you can make choices about the future but not the past and so forth."

> **"The arrow of time just comes from the fact that the entropy of the universe was smaller in earlier times and grows larger at later times" Sean Carroll**

Carroll explains that entropy also shapes how we perceive time: "There are good reasons why a person, considered as a series of people at moments in time with increasing entropy, feels that time flows in that direction. It's more of a psychological effect than anything else – we carry around in our minds a moving image of what we were a second ago, what we will be a second from now, and we're constantly updating on the basis of what we learn, how our surroundings change and so on. It's that riding the wave of the increasing entropy of the universe that gives us the perception of the flow of time."

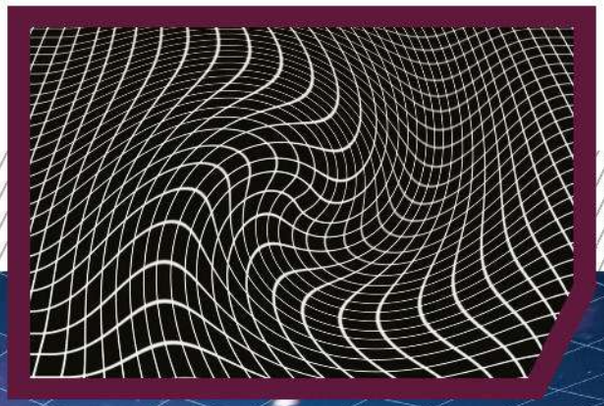
Italian physicist Carlo Rovelli goes even further in his 2017 book *On the Order of Time*, suggesting that entropy itself is also just a result of our perception. Consider the universe on the submicroscopic scale of

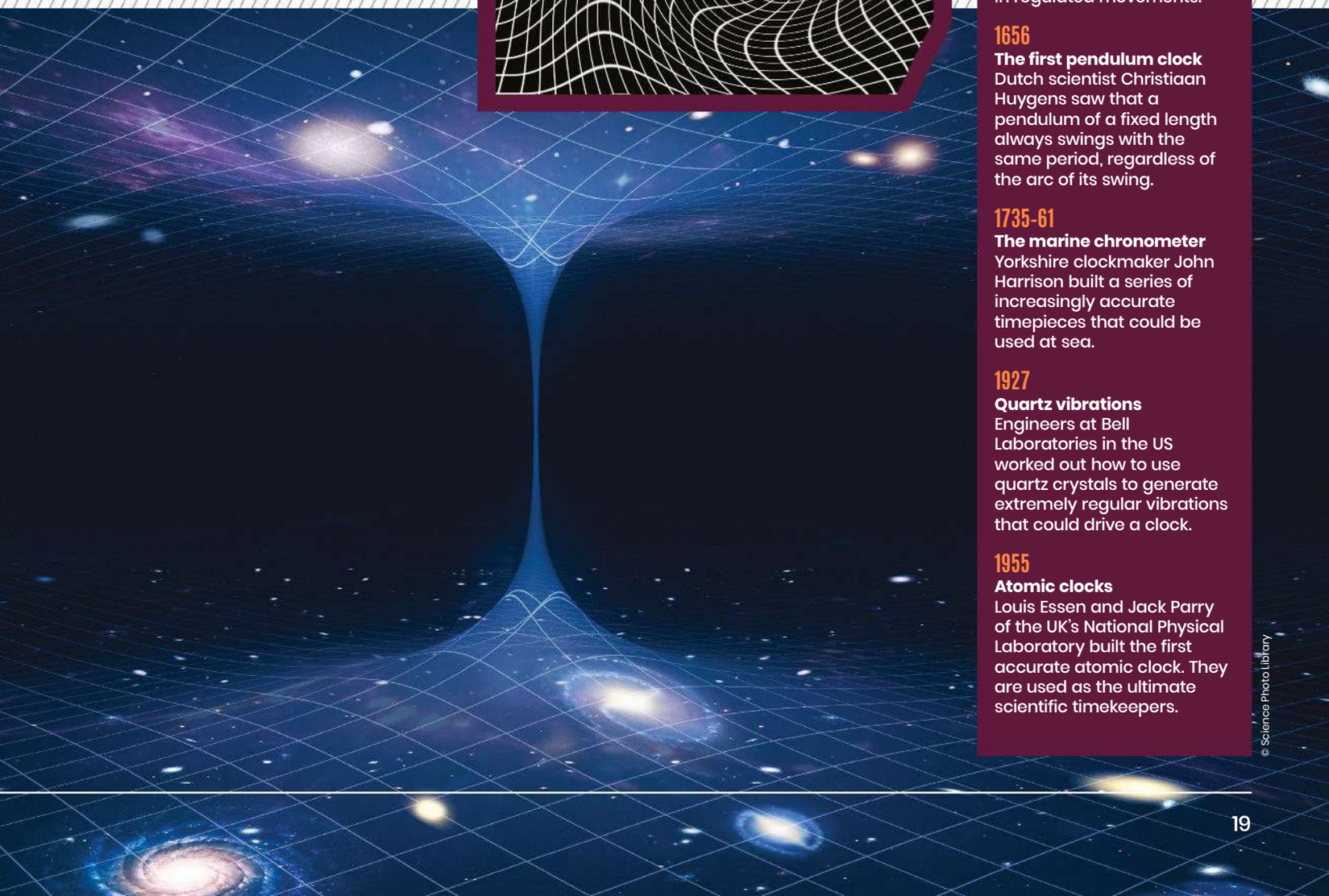
- Time is different depending on where you are in the universe, and thus isn't uniform
- Could wormholes exist between time as well as space?

quantum physics, Rovelli argues, and entropy becomes imperceptible. On the quantum scale, things happen in unpredictable ways that are very different from the certainties of everyday experience, but the forces that control interactions between particles are often what physicists describe as symmetrical. In other words, they're equally likely to run 'forwards' or 'backwards', with no favouritism for a particular direction in time. Look closely enough and the arrow of time disappears. Rovelli believes that the true nature of the universe is best described by a theory known as loop quantum gravity (LQG). In order to fulfil its goal of combining the quantum theories of the subatomic world with a description of gravitation and the large-scale universe in a so-called 'theory of everything', LQG suggests that space-time can be broken down into tiny chunks a bit like subatomic particles. There's a smallest possible unit of length and an equally imperceptible basic unit of time.

In LQG, reality is a vast network of 'events' – interactions between the complex quantum equations known as wave functions, describing both matter particles and chunks of space-time. Events have no special order in time, but it's our particular perspective on them, and the 'blurriness' of our large-scale overview, that give rise to a universe where entropy increases and there's an apparent arrow of time.

While LQG is still very much a work in progress, it does share one important point with the entropy-powered view of the universe. Both interpretations treat the flow of time as an 'emergent' phenomenon – one that develops from the large-scale behaviour of the universe rather than being baked in on the smallest scales. Most modern cosmologists and theoretical physicists take a similar view, but there are exceptions. For instance, in 2016 Richard A. Muller, emeritus professor of physics at the University of California, Berkeley, published *Now: The Physics of Time*, in which he argues





TIME'S EVOLUTION

3000 BCE
Tracking the seasons
Most living things have some 'time sense' in the form of adaptations to the seasonal cycles as Earth moves around the Sun.

2000 BCE
Water clocks
The first devices used to keep track of shorter periods estimated the passage of time through steady drips of water.

1500 BCE
Sundials
Sundials keep time by tracking the path of the Sun's shadow. Differences in its path throughout the year make them inaccurate.

3000 BCE to 1200 CE
Mechanical timekeepers
Clocks began to use escapement mechanisms that harnessed the power of falling water and released it in regulated movements.

1656
The first pendulum clock
Dutch scientist Christiaan Huygens saw that a pendulum of a fixed length always swings with the same period, regardless of the arc of its swing.

1735-61
The marine chronometer
Yorkshire clockmaker John Harrison built a series of increasingly accurate timepieces that could be used at sea.

1927
Quartz vibrations
Engineers at Bell Laboratories in the US worked out how to use quartz crystals to generate extremely regular vibrations that could drive a clock.

1955
Atomic clocks
Louis Essen and Jack Parry of the UK's National Physical Laboratory built the first accurate atomic clock. They are used as the ultimate scientific timekeepers.

© Science Photo Library

that the flow of time is a real phenomenon driven by the way that more time is created as space itself grows.

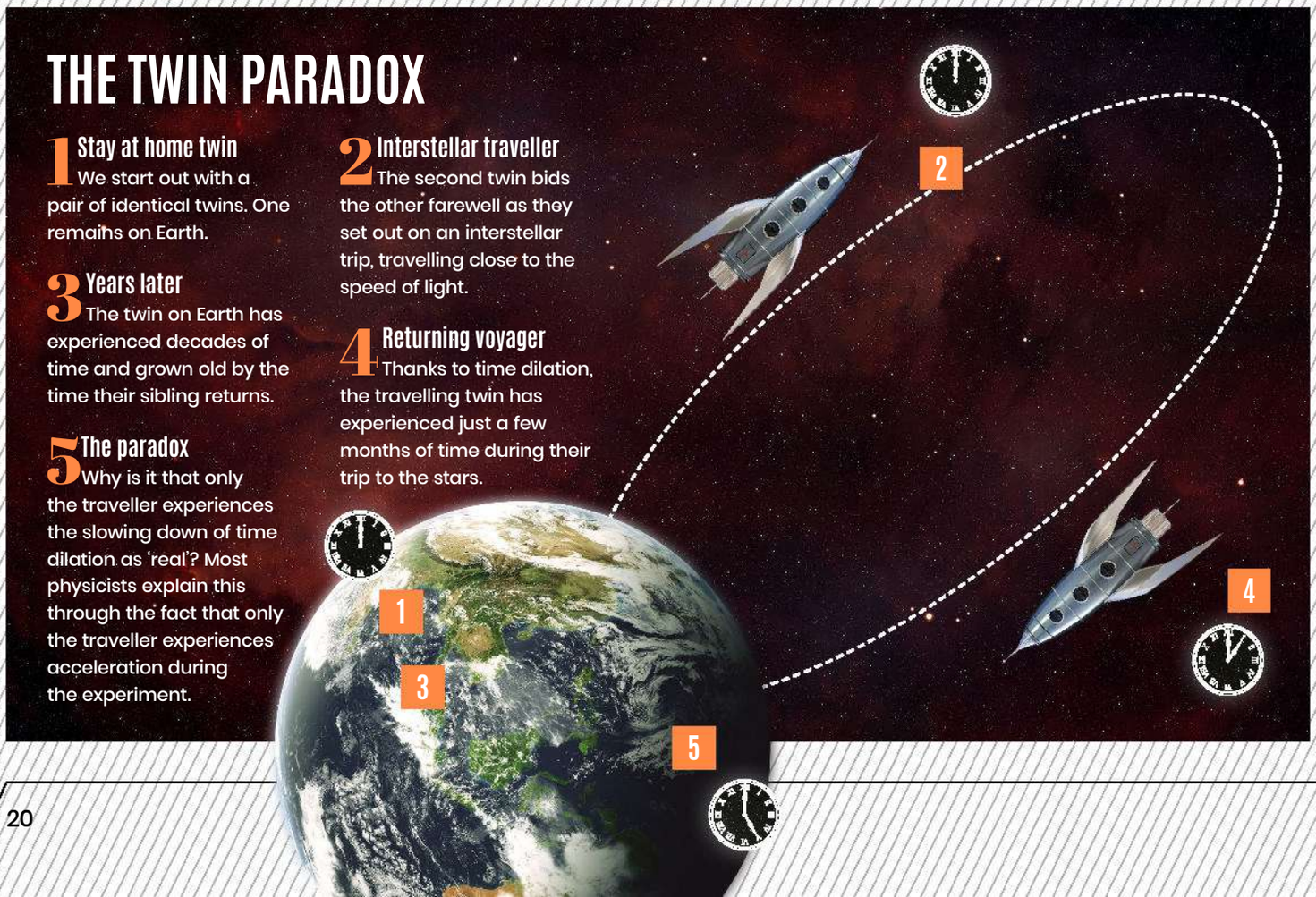
If the majority of physicists are right and the flow of time is 'emergent', then it's natural to ask what exactly time emerged from. How did it take on its unique properties and begin to flow? This preoccupied renowned cosmologist Stephen Hawking in the years before his death, and it's now at the centre of a new book by his long-time collaborator Thomas Hertog, professor of cosmology at KU Leuven in Belgium. *On the Origin of Time* chronicles the development of a theory known as quantum cosmology since the early 2000s – an attempt to model the quantum wave function of the entire universe in the first instant of creation.

Attempts to find a 'theory of everything' often falter when it comes to explaining the 'boundary conditions' of the present-day universe - phenomena such as the precise strength of natural constants, the operation of fundamental forces and even the number of space dimensions, all of which conspire to create a life-friendly universe. One popular solution to this problem has been to depict our universe as one particular bubble among many in an infinite multiverse. With an infinite range of possibilities on offer, the life-friendly nature of our particular bubble shouldn't be a surprise, because otherwise we wouldn't be here to see it.

Quantum cosmology takes a different approach, suggesting that none of the universe's present-day properties were baked in at the beginning. Instead they were subject to the same quantum uncertainty as everything else, evolving rapidly to reach their current values in the first few moments of creation. One of its most surprising findings is that, although we can trace back the expansion of today's universe and show that it has only existed for 13.8 billion years, there was no single instant when time began.

"The bottom line of my work with Hawking is definitely a picture of time in which time is an emergent quality of the universe," explains Hertog. "We went all the way down to the origin of time, if you wish, the Big Bang. We viewed that very early stage of the universe as a kind of basic layer of evolution of its own, in which the laws of physics progressively get forked, and the deepest layer there is the emergence of time."

But how do you even begin to construct the wave function of the entire universe? To do this, physicists rely on the so-called holographic principle – the idea that a description of an object with a particular set of dimensions is encoded onto a boundary surface with fewer dimensions. The object can be reconstructed if you 'read' the boundary surface in the right way. The idea is familiar from holograms – complex patterns encoded on flat photographic film that reproduce the properties of 3D objects when properly illuminated. The holographic principle suggests you can do something similar with four-dimensional space-time objects by decoding the information on 3D boundaries. Hawking made his name in the 1970s by applying these ideas to understand black holes. Quantum cosmology attempts to do the same thing for the entire universe.


THE TWIN PARADOX
1 Stay at home twin
We start out with a pair of identical twins. One remains on Earth.
2 Interstellar traveller
The second twin bids the other farewell as they set out on an interstellar trip, travelling close to the speed of light.
3 Years later
The twin on Earth has experienced decades of time and grown old by the time their sibling returns.
4 Returning voyager
Thanks to time dilation, the travelling twin has experienced just a few months of time during their trip to the stars.
5 The paradox
Why is it that only the traveller experiences the slowing down of time dilation as 'real'? Most physicists explain this through the fact that only the traveller experiences acceleration during the experiment.
1
2
3
4
5

TIME ACROSS THE UNIVERSE

As we look out across space, the limited speed of light means we see objects as they were when light left them at some point in the past, turning our universe into a cosmic time machine

Earth
Time at the object:
Now

The Sun
Distance:
150 million kilometres (93 million miles)
Time at the object:
8 minutes and 20 seconds ago

Jupiter
Distance:
At least 588 million kilometres (365 million miles)
Time at the object:
33 minutes ago

Pluto
Distance:
Up to 7.5 billion kilometres (4.7 billion miles)
Time at the object:
Up to seven hours ago

Proxima Centauri
Distance:
40.2 trillion kilometres (25 trillion miles)
Time at the object:
Four years and three months ago

Sagittarius A*
Distance:
25,640 light years away
Time at the object:
25,636 years ago, around the peak of Earth's last Ice Age

Andromeda Galaxy
Distance:
2.5 million light years
Time at the object:
2.5 million years ago, prior to the evolution of humans

NGC 4845
Distance:
65 million light years
Time at the object:
65 million years ago, around the extinction of the dinosaurs

Cosmic microwave background radiation
Distance:
46.5 billion light years*
Time at the object:
13.8 billion years ago, shortly after the Big Bang

MACS J0416.1-2403
Distance:
4.95 billion light years*
Time at the object:
About 4.3 billion years ago, shortly after Earth's formation

© Nicholas Forder

*Cosmic expansion has carried the most distant parts of the universe further away in the time their light has been travelling to reach us

The Laser Interferometer Gravitational-Wave Observatory tunnels capture minute shifts in the dimensions of space caused by gravitational waves as they pass through Earth

One of the most famous effects of relativity is time dilation: the slowing down of time for objects moving at high speed relative to observers viewing them from outside

"When Stephen and I used the holographic model to reconstruct the past of the time dimension," recalls Hertog, "we found that it had limits – when you delve all the way back to the Big Bang you sort of lose the dimension of time." Hertog describes the effect as something like a rotation – if you imagine time as a fourth dimension at right angles to the three space dimensions, then the extreme conditions of the early universe bend it so that time runs more slowly the closer you get to the moment of creation. The 'time' dimension becomes increasingly space-like, and eventually movement through time as we would understand it disappears completely. He's keen to point out that this does away with the need for a multiverse. "The key message of the last paper I published with Hawking is that the multiverse is gone. This is because of the fact that the dimension of time only extends so far back. To me this was a wonderful insight, because the multiverse comes with a whole list of paradoxes."

These strange conditions would only have affected the first instant of creation, when the entire universe was packed into a region far smaller than an atom, but if we could wind the clock back to this period of cosmic history, things would be very strange indeed. "Clearly when time sort of morphs into a space dimension, you're going to lose all notion of causality," says Hertog. It would be possible to move back and forth through the rotated 'imaginary time' dimension, while the progression of time itself would be slower and slower, and eventually stop completely. The universe in this pre-time state could have existed for an eternity.

For the moment, many of Hertog's intriguing ideas remain in the realm of theory, but if the holographic principle can be proven correct – perhaps through future observations of radiation and space-time distortions from the very edges of the observable universe – then quantum cosmology promises to be the beginning of an exciting new era for theoretical physics. It would be a fitting final legacy for Stephen Hawking, and an explanation at last for the true nature of time.

Giles Sparrow
Space science writer
The author of over 20 books on popular science, Giles holds a degree in astronomy and is an editor specialising in science and technology.

"When you delve all the way back to the Big Bang you sort of lose the dimension of time"
Thomas Hertog

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MICROBOT EXPLORERS

A new generation of all-access planetary probes will delve further than ever before

From the moment the Soviet Union landed the Lunokhod 1 lunar rover on the Moon in November 1970, scientists and astronomers have been working tirelessly to create more efficient and effective methods for searching a planet's surface. We have seen rovers, landers and probes, but a team from the Department of Mechanical Engineering at the Massachusetts Institute of Technology (MIT) is working on microbots, the next generation of planetary investigators. These tiny, spherical robots – often no larger than a baseball – are able to hop, bounce and roll around the surface of a planet, get into crevices and navigate obstacles in ways that traditional rovers are unable to.

Within the next 50 to 60 years, engineers are hoping to reduce microbots to just ten centimetres (four inches) in diameter and have them weighing no more than 100 grams so that they are able to get themselves into hard-to-reach places. They would be constructed from lightweight polymers and carry miniaturised scientific equipment for research. Many of the key components encased in the machines will be around the size of a coin, with a mass spectrometer measuring just 0.6 cubic centimetres (0.04 cubic inches) and the four-gigabyte hard drive only just larger than a two-pence piece or a dollar coin.

The idea is to deploy hundreds of microbots on the surface of a planet, using an orbital craft to carry them and an air-bag system to ensure they're intact when they hit the planet's surface. From there, the microbots will spread out in teams, scouring the planet's surface and finding their way into lava tube caves. This will enable in-situ examinations of the planet's composition, history and chemical structure. They will then send this information back to the surface, where it can be stored and communicated to teams back on Earth.

The microbots would sometimes have to work in a relay to get the information back to the surface, as electromagnetic waves struggle to get through rocky structures. This means that the information would be

© Adrian Chesterman

transmitted using high-frequency waves, jumping from bot to bot until the signal is eventually able to be picked up on the surface.

A dielectric elastomer actuator – an elastic dielectric film placed between stretchy electrodes – creates the hopping movement of the microbots. When current is passed through this, the electrodes are stimulated and laterally expand the film. This rapid expansion enables a microbot to hop on its bistable leg and travel across the planet's surface, easily traversing obstacles such as rocks. Each hop could take a microbot as far as a metre (3.3 feet), which would enable it to travel across dozens of metres every day, collecting important scientific information as it goes.

Mars would be one of the first obvious ports of call for this generation of planetary explorers. There has been an awful lot of analysis of the Red Planet recently, but the opportunity to go deeper than ever before will be hard to pass up. The Moon, with its pockmarked surface, will be another key area for the microbots to be deployed, but any planet or satellite with an inhospitable, rocky surface will be on the radar for these access-all-areas robots.

"These tiny, spherical robots are able to hop, bounce and roll around the surface of a planet"

1 Size matters
The miniature robots will ideally only be around ten centimetres (four inches) in diameter, enabling them to reach tiny gaps.

2 Equipment
They'll be fitted with a processing unit, camera, mass spectrometer, hard drive, sensors and other devices for measuring data.

3 Inside a planet
The microbots will enter crevices and caves in order to search for data hidden beneath the surface.

4 Low power
Due to the efficient nature of the hopping mechanism, low-energy and low-weight fuel cells can be used for power.

5 Teamwork
Thousands will be deployed on the surface, enabling them to spread out and operate in teams.

6 Materials
Each device will be constructed from a lightweight but durable polymer, which should reduce cost and weight.

7 Deployment
Microbots will be dropped by an orbital craft from above a planet's surface and will use air bags to cushion their landing.

8 Hopping
Using a rapidly expanding dielectric film, the robots will be able to hop up to a metre (3.3 feet) at a time in any given direction.

9 Communication
Teams of microbots will relay information between one another on the surface in a chain of high-frequency waves.

BIO+

Dr Thomas Zurbuchen

Zurbuchen grew up in Switzerland, where he studied physics at the University of Bern. After moving to the US he became professor of space science and aerospace engineering at the University of Michigan, where he also founded the Center for Entrepreneurship at the College of Engineering. From 2016 until 2022, he led NASA's Science Mission Directorate.

Dr Thomas Zurbuchen

"Finding life elsewhere is critical"

The man known as Dr Z stepped down as head of NASA's Science Mission Directorate on 31 December 2022, having served in the post for six years – a longer continuous term than any of his predecessors

Interviewed by Mike Wall

What do you make of your time at NASA's Science Mission Directorate?
I would talk about it in two ways. The first one is the personal side, and the second is the community side. It turns out that the second one matters more, but I'm less clear about that because I think it tends to be that history proves what is the right answer. There are other opinions, so mine kind of matters less.

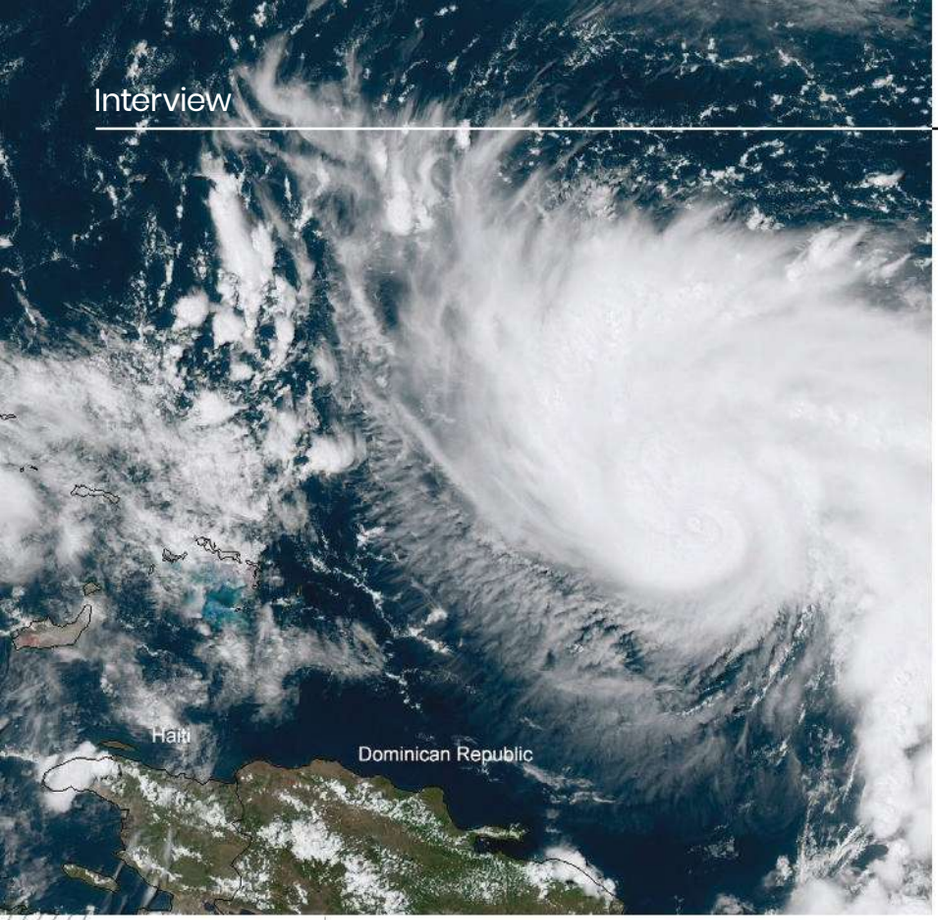
I'm in awe of having the front-window view of all of science. I get to see the first picture ever taken on a mission – in the hallway, somebody's handing it to me. I've just been in awe of the amazing power of space and the amazing power of science to really inspire and to excite. That's kind of my personal view.

I think on the community side, what we have experienced in the last six years is an enormous growth in many different dimensions. If you take any six-year period, you would be hard-pressed in the history of NASA seeing one that, as an aggregate, created more success. Of course, that's not because of me, certainly, alone. It has to do with the support that we've gotten from Congress, from the various White Houses and also the execution by industry-government teams.

You were steering the ship when a lot of very high-profile missions were developed and launched. Do you have any favourites?
I want to mention Webb, because what we saw in the final years [of development] and the deployment, I have not found a single person that expected it to go as well as it did. I've not found anybody, and I interviewed everybody. I actually kind of

© Getty; Alamy

The James Webb Space Telescope was one important launch during Zurbuchen's tenure at NASA



The GOES satellites track storms and monitor the weather

tended to be a little bit more pessimistic than some of the people on the team, which was perfectly fine.

Think of it as having an 18-hole golf course [and sinking] hole in one after hole in one. That's what the team did here at the end. Now, I want to also hasten to say, we didn't start there. That first year I got there, we had a little bit of an accident. Staying with the golf example, [it was] like breaking every single driver and losing the ball. We had some real challenges. But the point is, look at what they did. I will never forget that. I'm just so proud. It's like a sports team: on Sunday you know how good the team is, not how hard they train. And look at this team... it stunned the whole world.

Another mission that I just love and I think about all the time is the GOES [Geostationary Operational Environmental Satellites] series. GOES 16 was the first mission I launched in my job and, for what it's worth, was the first launch I ever saw in person. Every time I look at their forecasts – and especially when I look at hurricane forecasts – I know that this mission that we launched together and built together with our cross-agency partner, NOAA [the National Oceanic and Atmospheric Administration], is in fact changing the lives of citizens. For me, that's just empowering. And of course, landing on Mars. There aren't many thrills that are more scary and also more exciting – and seeing the first image show up after you were sweating blood back there. We did that twice since I've been on the job, once on InSight and the other one on Perseverance.

The last decade has seen an increased interest in space and space science among the general public. To what do you attribute that, and how much of that is a goal of NASA's?

We've seen this growth, and we're excited about it. The way I think about it is, what I really seek to do is inspiration. The work that we do, science, is all about understanding nature in a new and better way. Nature is amazing, right? I think of nature in a very similar way that many people do, frankly, when they talk about their religious beliefs – they think about something that's really important and bigger than themselves. I think that way of nature. When you listen to children – or grown-ups who behave like children, which is the right way to behave – that curiosity, that understanding, is really inspiring. That's one thing. And the second one is seeing teams doing the impossible. That's also inspiring. We have both [at NASA], especially if you bring diverse teams together where many people see themselves, and we're better off. And again, I don't want to take credit – we have a much stronger social media presence. We use different channels, we use different partnerships; we have an amazing communications team, and I think our leaders actually understand that this matters and are spending the effort on it.

That's one piece. I think the other piece is the emergence of commercial space. The space discussion is more interesting now because there are more players, and some of them are really colourful characters. Change is interesting – it attracts attention. And for us, much of it has created enormous opportunities for science. Some of them have yet to bear out, but [there are] opportunities that relate, for example, to lower launch costs and the workforce in aerospace.

The way I always think about it is, I live through the lives of my students that were in my classroom ten years ago or so. They're out there leading these things. Companies that they started, some of them that they joined as well as some of the other companies that have been with us for a while – they've also reinvented themselves. I think that's another part of that energy. That's why it's so important that we don't define what we do kind of in separation from that – you want to talk about it from the perspective of the entire community. We're excited about these new players, as well as some of the other ones.

What sort of advice would you give to your successors? How can they keep NASA science growing and moving in the right direction?

In the first speeches that I gave when I took the job, I said there are three priorities here. The first priority is build the best team. And the best team is not the most experienced, by the way. There's experience there, but there's also new thought. There are new ideas; there's diversity built around it. And gain the trust of that team. If you can do that, you can delegate a lot of stuff. The second one is recognise that many of the missions you're going to work on are already in the water. They're moving forward, and your job is to do a great job and trust. Trust is absolutely critical for all stakeholders; do the best job in making decisions and moving it forward. Execute – focus on programmatic performance, not just technical performance. Both matter.

The third one is develop strategic insights. Look at the pattern, what is changing, and take advantage

of opportunities. There are new spacecraft-as-a-service types of models; I think that's really interesting. There are new ideas that are focused on much faster development. I think we have been too slow in some instances. But whatever the ideas are, the point is focus on number one and number two first. You're going to want to learn from the community overall to get the final advice. And when you do all of these things, think of community with a capital C. It's not just people who are on your floor, or in NASA headquarters. It's also the company people out there, the academics, the startup community, the funding community, the government stakeholders, the White House stakeholders. Really make sure that they understand what's happening and bring them on board.

During your tenure you sought to normalise the search for alien life and make that more a part of the mainstream scientific process. Astrobiology was historically a little on the fringes, and it seems like you've really embraced that as a core NASA priority. We've seen that with Mars sample return, and with the recent effort to look into unidentified aerial phenomena. Do you see that as something that you have overtly tried to do?

If you felt that was the case, I would be really proud of it, because I happen to believe it's one of the most important things we could be working on. It's also what people care about, and it actually matters to me what people think. I do believe finding life elsewhere is absolutely critical as an objective. And by the way, even when I was here, I was part of an authorisation law where we were given the task to do that. I was really glad to receive that task, and I've taken it seriously.

Is there anything about your tenure over the last six years that you want to stress has been particularly important or particularly revelatory?

First, I want to just say how proud I am of the team we put together here, the leadership team. If you've paid attention, you'll realise it looks really different than it did before. You can really see the power of diversity and coming together, and I hope that people observe that and are encouraged.

I also want to tell you how excited I am about the growth of space in all domains – growth that I really hope we'll see even more of. There's much more possible. We're taking observations of our own planet and turning it into actionable information that makes people's lives better. A farmer gets more gain out of the work that they do in the field based on the information that we have. Over time, we've helped our good friends and cross-agency partners predict weather even better, because we understand the physics of clouds, for example.

There is a huge opportunity. And with the rapid changes that we see all around us, our entire research portfolio needs to be a lot more like the Manhattan Project than some kind of research and analysis shop. For me, that comes from commercial partners and government partners coming together. If there's anything I learned, and maybe my final point is, how many opportunities arise if people come together who are different from each other, if organisations come together that are different from each other.

"The work that we do is all about understanding nature in a new and better way"

When you say that it needs to be more like the Manhattan Project, is that because the threats that we're facing – climate change, deforestation, those sorts of things – are existential, or potentially existential?

I would say that the difference between Earth science today and Earth science 30 years ago is that 30 years ago, we knew from our models that we had decades for change, and to implement change. The change that we're observing now happens in a short time relative to a decade. The timescale of change is fast enough – and affects humans enough – that the responsiveness needs to be a lot faster than what we have done in the past. That's what I'm really talking about. It's like playing hockey – you need to skate where the puck is going to be and stay agile as you learn how things are changing on the playing field. For me, that is really how Earth science is evolving. And what an opportunity to add value, not just on weather but also in so many of the other dimensions of life.

Zurbuchen announcing the name of the Mars 2020 rover

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FOCUS ON

ANDROMEDA CRASH TRIGGERED A MASS GALACTIC MIGRATION 2 BILLION YEARS AGO

The influx of stars into our neighbouring galaxy reflects a violent event in the Milky Way's past

Reported by Robert Lea

Astronomers have discovered new evidence that Andromeda, the galaxy next door to our own, grew by merging with another galaxy. The event triggered a mass migration of stars into the galaxy. This event suggests that the migration of stars to Andromeda – also known as Messier 31 – and the galaxy's growth history is very similar to that of the Milky Way. That means the findings have implications for our understanding of both galaxies. The evidence came in the form of observations of the individual motions of almost 7,500 stars in the inner halo of Andromeda, showing these stars had begun their lives as part of another galaxy that merged with Andromeda around 2 billion years ago.

Scientists have long predicted that large galaxies have grown to their current sizes via collisions and mergers throughout their history, but the patterns in the motions of stars that could confirm this have been elusive. The investigation was conducted by an international team of astronomers using the Dark Energy Spectroscopic Instrument (DESI) on the Nicholas U. Mayall Telescope at Kitt Peak National Observatory, operated by the National Optical-Infrared Astronomy Research Laboratory (NOIRLab). "Our new observations of the Milky Way's nearest large galactic neighbour, the Andromeda Galaxy, reveal evidence of a galactic immigration event in exquisite detail," lead researcher and NOIRLab astronomer Arjun Dey, said. "Although the night sky may seem unchanging, the universe is a dynamic place. Galaxies like Messier 31 and our Milky Way are constructed from the building blocks of many smaller galaxies over cosmic history. "

The majority of stars in the Milky Way's halo are also believed to have originated in another galaxy, finding a new galactic home during a massive merger event between 8 and 10 billion years ago. Looking at relics of a previous merger and stellar migration event in Andromeda could help astronomers hunt for similar artefacts in our own galaxy. "We have never before seen this so clearly in the motions of stars, nor had we seen some of the structures that result from this merger," researcher and University of Edinburgh astrophysicist Sergey Koposov said. "Our emerging picture is that the history of the Andromeda Galaxy is similar to that of our own galaxy, the Milky Way. The inner halos of both galaxies are dominated by a single immigration event."

To trace stellar migration, the team turned to DESI due to the fact that it's the most powerful multi-object survey spectrograph in the world, capable of measuring the spectra of more than 100,000 galaxies in a single night. "This science couldn't have been done at any other facility in the world. DESI's amazing efficiency and field of view make it the best system in the world to carry out a survey of the stars in the Andromeda Galaxy," Dey added. "In only a few hours of observing time, DESI was able to surpass more than a decade of spectroscopy with much larger telescopes."

The Andromeda Galaxy, also known as Messier 31

8 BILLION YEARS TO MILKOMEDA

How the night sky might change as the Milky Way and Andromeda collide

Present day
Andromeda is a faint smudge, about the size of the Moon, to the left of the Milky Way.

In 2.5 billion years
As Andromeda approaches, it becomes much larger and brighter in the sky.

In 4.3 billion years
Andromeda now spans half the sky, rivalling the Milky Way in magnificence.

In 4.4 billion years
As the galaxies begin to overlap, the increased gas density generates star formation.

In 4.5 billion years
The galaxies become an amorphous mass at the height of the collision; star formation continues.

In 4.6 billion years
As the galaxies move apart, both will show clear signs of tidal distortion, with visible tails.

In 6 billion years
After the frenzy of star formation, little gas is left as the galaxies meet for the last time.

In 8 billion years
Two become one: the core of a newly merged giant elliptical galaxy – Milkomeda.

18 SPACE APPS YOU'VE GOT TO DOWNLOAD

From planetariums to telescope control, be prepared for all things space and astronomy at the touch of a button

Written by Nick Howes

Apps on our mobile devices have transformed the way we work and live. From opening doors in our cars to ordering food from a supermarket or restaurant, the ability to access the entire internet with a computer several million times more powerful than the one that sent humans to the Moon residing in your pocket has been a revelation over the past decade or so.

For astronomers, the 'giant leap' this has enabled means that you no longer have to lug out cumbersome star maps the size of a broadsheet. Learning your way around the sky using augmented reality makes astronomy more exciting than ever – especially for younger people. Some may argue that 'traditional' methods are still the best, and that may be true to become a real expert, but the helping-hand apps which can give you a head start in your observing are here to stay, used by millions of people – even those with only a casual interest in the sky. Now, with several low-cost virtual-reality headsets in many high-street stores that you can easily clip your phone into, the options to observe and identify millions of objects have never been better.

Apps for astronomy are not just confined to planetariums in your pocket. Over the past few years, apps have enabled remote control of telescopes, quite advanced scientific analysis and a whole lot more. Here we dive into just a few of the ones we think are the must-have apps for your Android or iOS device.

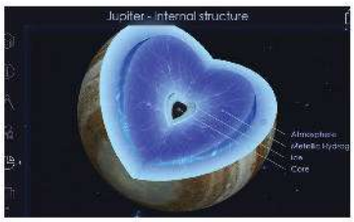
PLANETARIUM APPS

SkyView

Operating system: Android and iOS
Best for: Augmented-reality views of the night sky and satellites flying overhead
Level of astronomer: Beginner and upwards
Cost: Free

This free application really packs a punch when it comes to touring the night sky. With a huge integrated database of all the popular objects, it has a night-vision mode to preserve your dark adaption and a time-travel function to allow you to jump forwards and backwards, planning your observations for the whole year. The star of this show is its augmented-reality feature, which allows you to point your camera at the sky and let it overlay – once it knows your position via GPS – detailed information on the objects you're looking at, as well as constellation overlays and beautifully rendered graphics of objects. Plus you can zoom in and out to get even more information.

SCORPIUS
CONSTELLATION, ABOVE HORIZON
Scorpius is a large constellation located in the southern hemisphere near the center of the Milky Way.



Saturn
It's possible that Saturn's rings have been around since the beginning of the Solar System – almost 4.6 billion years ago.

Star Walk - Night Sky Map

Operating system: Android and iOS
Best for: Beautiful graphics and engaging young people in the night sky
Level of astronomer: Beginner and upwards
Cost: Free

Augmented reality comes back with this multi-platform app. The level of detail in some of the rendered images of planets and the comprehensive look at our Solar System's objects in general is a delight. What makes this app stand out is the rendered graphics of the planets. It enables children and adults alike to view details that their telescope may never show them in a way that is really engaging. Not only does it show the planet you may be interested in's surface, it adds real scientific data and understanding to how the planet works and was formed.

Stellarium Mobile - Sky Map

Operating system: Android and iOS
Best for: A comprehensive database of objects, and one of the original and best planetarium apps
Level of astronomer: Beginner and upwards
Cost: Free

A favourite among many astronomers, this app, which is also available on PC and Mac, as well as Linux machines, has one of the best databases of objects of any planetarium. With plug-ins and upgrades galore, its 600,000-plus object database will teach you more about night-sky objects than you could probably ever want to know. With in-app purchasable updates, you can add additional data for comets and much more. The photo-realistic views really do help make this a delight to work with. As with most planetarium apps, it has a night-vision mode, overlays of constellations – including some beautifully created graphics depicting different star lores and cultural influences – and satellite tracking so you can observe Hubble or the ISS flying over.

SkEye Pro

Operating system: Android
Best for: Vast database and comet information
Level of astronomer: Advanced
Cost: £9.99 / $9.99

This brilliant piece of software has a very detailed list of stars, objects and information, as well as an extensive and updatable two-line element set and comet database. But the killer feature with this is the virtual digital setting circles. Strapping your phone or tablet to a telescope and using the object locater to guide you to the thing you wish to see turns any standard non-Go-To telescope into something a lot more powerful. It's not as accurate as precision Go-To systems, but with a wide-field eyepiece in on a big Dobsonian, it's brilliant and more than accurate enough.

Planetarium VR

Operating system: Android
Best for: VR headsets
Level of astronomer: Beginner
Cost: Free

While many apps support augmented-reality modes and overlays, Planetarium VR takes this a step further, with full 3D support for low-cost VR headsets. A relatively limited object database compared to others does not detract from the fun. A standard 'swipe' mode has also been added, but this app is really at its best when used with a VR headset.

LUNAR AND PLANETARY OBSERVATION AND EXPLORATION APPS

Moon Atlas 3D

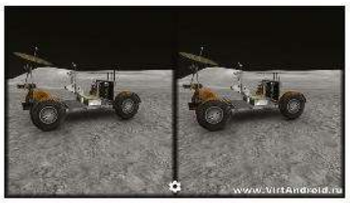
Operating system: Android
Best for: Detailed lunar observations
Level of astronomer: Beginner to advanced
Cost: Free

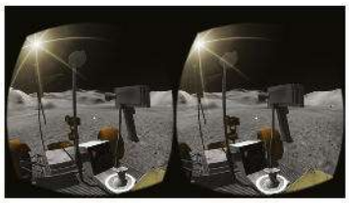
The late, great Sir Patrick Moore spent a lifetime learning about and mapping the Moon. We can only imagine how much an app like this would have enthralled him to see, with a high-resolution lunar surface map, over 8,000 craters labelled and detailed, all of the Apollo landing sites marked as well as the lunar phases and shadows rendered in stunning detail. Add to this telescope mode and you have the perfect companion for lunar viewers.

Apollo 15 Moon Landing VR

Operating system: Android
Best for: A fun way to explore the Moon
Level of astronomer: Beginner
Cost: Free

Most of us would love to be an astronaut, and no greater achievement in human spaceflight occurred than in the late 1960s and early 1970s with the Apollo missions. The first Apollo mission to take a rover, and one of the most important scientifically, was Apollo 15. This wonderful app, which is almost like a game in how it runs, takes you on that journey from launch to touchdown. Then, using Google cardboard or any low-cost 3D headset, puts you in the shoes and driving seat of David Scott and James Irwin as they explore the Hadley Rille landing site. It's immense fun if nothing else.





Lunar Map HD

Operating system: Android
Best for: Geological survey data of the lunar surface
Level of astronomer: Intermediate to advanced
Cost: £1.39 / $1.49

This is a true hardcore lunar fan app that will take you places you'd never imagined. Using data from the United States Geological Survey to give you a true three-dimensional relief map of the lunar surface, augmented with the Lunar Reconnaissance Orbiter's wide-angle camera data, this app – with close to 9,000 craters and lunar surface features mapped – goes above and beyond what any other lunar app does. It has colour-coded topographical maps for those who wish to understand the true shape of the lunar surface, with links to online databases for yet more information. It comes in both a pro and lite version, but for the small amount that the HD version costs, it's well worth every penny.

Pluto
Once considered the mysterious 'Planet X', the former planet Pluto was demoted to the status of 'dwarf planet' in 2006 with the discovery of other similar sized bodies in the Kuiper Belt, reducing the Solar System to just eight planets.
Pluto is composed of a rocky core, surrounded by a layer of water, nitrogen and methane ice with a total mass approximately 18% of Luna.
The dwarf planet's orbit is both highly eccentric and highly inclined and is considered chaotic as it is not possible to create a simulation that will remain accurate beyond a few million years.
To date no robotic probes have come close enough to Pluto to photograph it,
Pluto
Saturn
Vesta
Ceres
The Belt

Solar System Explorer 3D

Operating system: Android through Amazon Appstore
Best for: Pretending you're Voyager 2
Level of astronomer: Beginner
Cost: Free

The Voyager grand tour took robotic exploration to locations no other spacecraft in history has since matched. But as it's now over 30 years since the last flyby of Neptune, we're left only with memories and Hubble Space Telescope images. This app takes you not only to the vast gas outer planets visited by Voyager, but inwards towards Venus and Mercury and across the asteroid belt, too. Data for the high-resolution images comes from a plethora of NASA missions and is augmented by ground-based data where parts are perhaps missing. You can also swing to the moons of Jupiter, Saturn and beyond, as well as Ceres and Vesta. The music can be jarring, but can easily be turned off if it becomes too much of a distraction.

Mars Globe

Operating system: iOS
Best for: Superb app for fans of the Red Planet
Level of astronomer: Beginner to advanced
Cost: Free

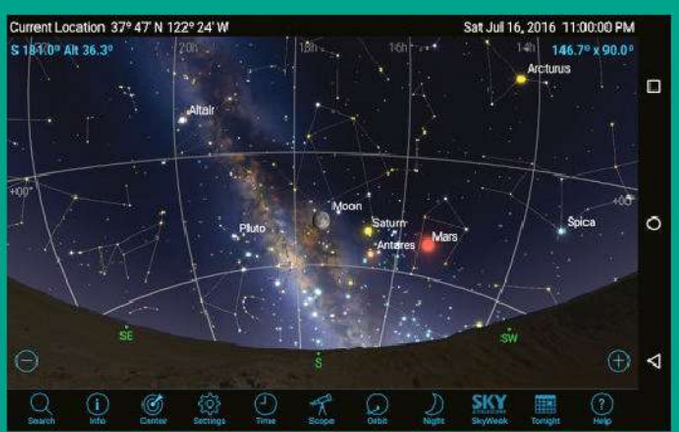
Until we get boots on the ground of the Red Planet, humankind will rely totally on the work of robotic landers, rovers and orbiters to send us detailed images of what it may be like to visit Mars. This app for iOS devices allows you to have a fly-through tour of the Martian surface using very high-resolution orbiter data overlaid with topographic data to give it accurate and outstanding relief feature visualisations. With over 1,500 surface features annotated and linked, this is a real gem of an app, taking you to Mars in a way that most likely won't be possible for at least a decade or more.

TELESCOPE INTERFACE AND CONTROL APPS

SkySafari 7 Pro

Operating system: Android and iOS
Best for: Telescope control and planetarium
Level of astronomer: Beginner to advanced
Cost: £19.99 / $19.99 Android, £19.99 / $19.99 iOS

With one of the largest star databases of any app – with over 25 million stars and 740,000 galaxies – this will map down to magnitude +18 in the pro version. It integrates support for DSS image downlink, has the Abell and Hickson galaxy cluster catalogues as well as the full New General and Messier catalogues, integrated DSC support with multi-star alignment and, best of all, full telescope control for Meade, Celestron, Sky-Watcher and more via interfaces that work over SkyFi and SkyWire.



SATELLITE OBSERVATION APPS

ISS Live Now: View Earth Live

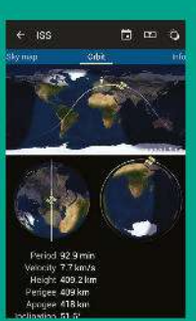
Operating system: Android and iOS
Best for: Seeing the ISS from the ground up and looking down from Earth orbit
Level of astronomer: Beginner to advanced
Cost: Free

This app gives you a handy heads up as to when the ISS will be passing overhead. It also links in to the live HD cameras which are pointing down at us from the ISS. Being able to see aurorae from orbit, the lights of major cities and much more is a real thrill.

Heavens Above

Operating system: Android and iOS
Best for: Satellite spotting
Level of astronomer: Beginner to advanced
Cost: Free

Containing data for thousands of satellites, you can look out for iridium flares and uplink and downlink information for radio satellites to enable radio ham operators to listen in or, in the case of the ISS, sometimes even make voice calls to and from the station. Also a great way to impress friends when you say to look up and a bright Iridium-flare flash occurs in the sky.



GENERAL ASTRONOMY APPLICATIONS

NASA Visualization Explorer

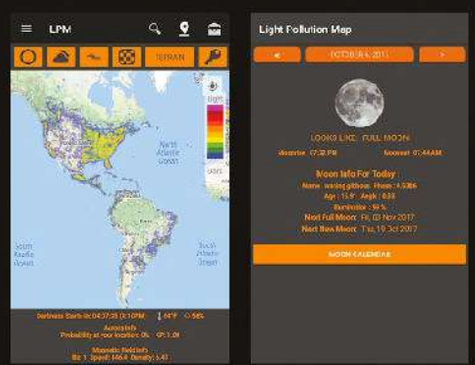
Operating system: Android and iOS
Best for: Getting the latest information on the activities of the world's leading space agency
Level of astronomer: Beginner and up
Cost: Free

This app is updated every day with news, information, science facts, videos and much more from NASA. It will keep you on top of the latest work being conducted at all of the NASA centres. With plenty of Hubble and James Webb Space Telescope images and all the news on returning to the Moon with Artemis, it'll be one space-based app you'll not wish to be without.

Light Pollution Map - Dark Sky

Operating system: Android and iOS
Best for: Finding the perfect observing or imaging locations
Level of astronomer: Beginner to advanced
Cost: Free

With light pollution an ever-increasing problem for many amateur and professional astronomers, an app that gives you a handy guide to where the best locations are to avoid the sodium curse is a godsend. This app not only manages that well, but also gives you data on aurorae, meteor showers, eclipse alerts, Moon phases and more. It's like a pocket Swiss army knife for astroimagers and observers alike.



ASTROIMAGING AND SUPPORT APPS

Telescope Flashlight

Operating system: Android
Best for: Helping you find your equipment in the dark
Level of astronomer: Beginner to advanced
Cost: Free

The number of times that every astronomer has wished they had a red-light torch and found that the batteries were dead, or that they'd lost or left it somewhere, is huge. Having a phone or tablet in your pocket that can light up that dark field and not destroy your night vision would be ideal. The only issue with this is that if you have to turn your phone on first to launch the app, the glaring-white screen may kill it anyway.

Telescope Calc

Operating system: Android
Best for: Working out the parameters for your telescopes and eyepieces
Level of astronomer: Beginner to advanced
Cost: Free

This is one of those handy little apps that does a lot and very simply. This app is one pretty much every astronomer could use, with options to set up optimal eyepiece and telescope combinations for specific observations. If you want to know the magnification or field of view your eyepiece will deliver in the telescope you add it to, this is a very useful app to have ready.

Field of View Calculator

Operating system: Android
Best for: Helping CCD imagers work out their imaging options
Level of astronomer: Intermediate to advanced
Cost: Free

Atik is renowned for making superb cameras and intuitive imaging software. This is a nice, free app for your device that calculates the field of view for many popular objects relative to your telescope, its optical configuration and the CCD you are using. Knowing the spec of the CCD, this app could be used to support many other cameras set-ups too.

FOCUS ON

DWARF PLANET HAS A MYSTERIOUS RING

The feature is so far from the world's surface that its material should have coalesced into a moon... but somehow, it didn't

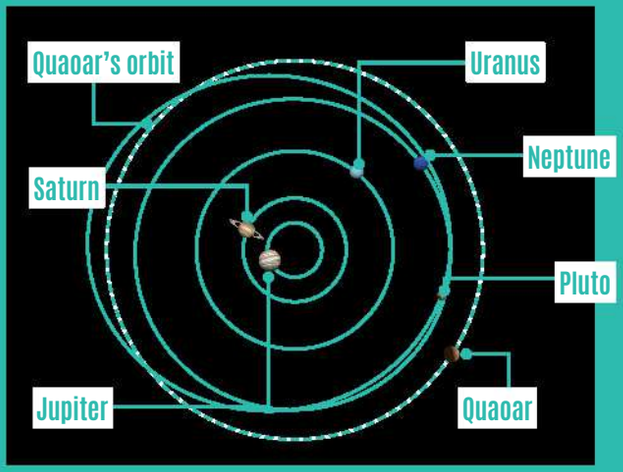
Reported by Tereza Pultarova

A mini-planet orbiting in the frigid outer reaches of the Solar System has a Saturn-like ring of dust and debris that defies the rules of physics. The planet in question is called Quaoar, and it's the seventh largest of the known dwarf planets. Discovered in 2002 and measuring about 1,121 kilometres (697 miles) wide, Quaoar is one of the so-called trans-Neptunian objects, small planets orbiting beyond the Solar System's outermost planet, Neptune. Residing in the Kuiper Belt, the doughnut-shaped ring of rocky and icy debris in the outer Solar System, Quaoar is a proud owner of its own moon, the 160-kilometre (100-mile) wide Weywot. And a recent observation campaign revealed that it also has a ring of material in its orbit.

That by itself wouldn't be so special. The gas giant Saturn is known to possess a whole series of rings. Jupiter, Neptune and Uranus also have some. One other trans-Neptunian object – Haumea – has been found to have a ring, and the space rock Chariklo that orbits between Saturn and Uranus also has one. So what exactly sets Quaoar's ring apart?

Quaoar's ring is at a very unusual distance from its parent body. In fact, before astronomers discovered Quaoar's ring in observations from several telescopes conducted between 2018 and 2021, they thought that it was impossible for a ring to exist at such a distance. With a radius of about 3,885 kilometres (2,420 miles) from Quaoar's centre, the ring is so far away from the dwarf planet that its gravity should no longer be able to keep the material dispersed. Instead, it should coalesce under its own gravity and form another moon, just like Weywot. By not having done that, the ring has breached what astronomers call the Roche limit – the first known ring around a celestial body to have done so.

"What is so intriguing about this discovery around Quaoar is that the ring of material is much farther out than the Roche limit," Giovanni Bruno, an astronomer at Italy's National Institute for Astrophysics (INAF), said. "As a result of our observations, the classical notion that dense rings survive only inside the Roche limit of a planetary body must be thoroughly revised."



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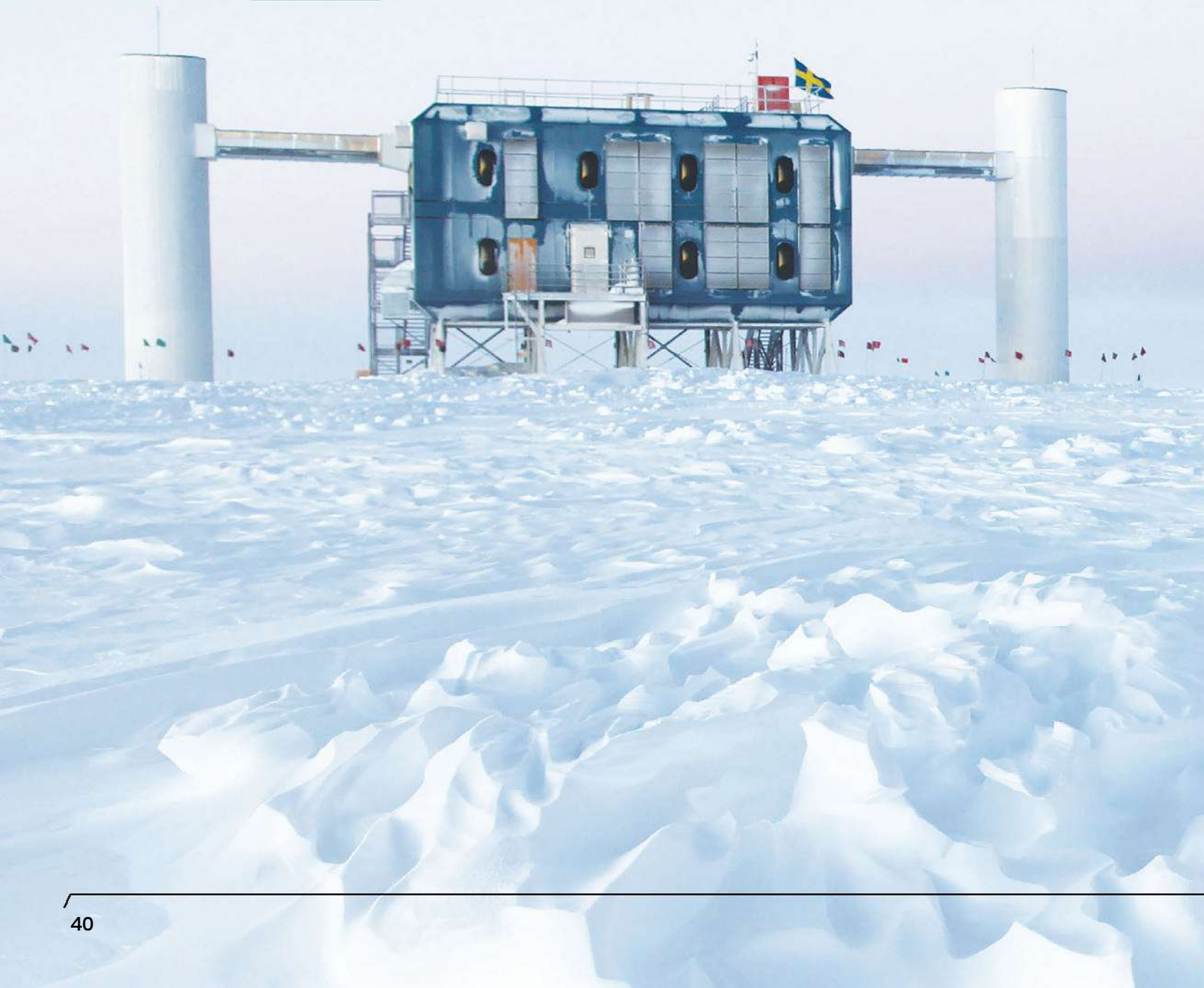
SPACE LAB ANTARCTICA

Antarctica may be at the bottom of the world, but as the coldest, driest and highest continent on Earth, it's ideal for observing the universe

Reported by Paul Cockburn



'Wrap up warm' has long been a mantra among astronomers everywhere, given that so much observation of the cosmos has to take place out in the open and at night. However, if you've ever grumbled about surviving a few hours outside during a cold British winter night, just remember it could be worse – you could be in Antarctica, or even at the South Pole.

"I still remember the first time I flew down there," says Kael Hanson, director of the Wisconsin IceCube Particle Astrophysics Center at the University of Wisconsin-Madison. "It was early November, which was just when the station opens for most people, and it was about -45 degrees Celsius (-49 degrees Fahrenheit). It was quite a shock just to get off the aeroplane and be out in that cold. It's blinding bright too, unbelievably bright, because you have all this snow and everything is reflecting in your face. It's also at altitude. The first couple of days you find yourself catching your breath. Sometimes you wake up sort of gasping for air, just because of the altitude. It's an incredibly extreme environment to live in."

Extreme it might be, but that's what makes Antarctica and the South Pole such an ideal spot for setting up your telescope. According to theoretical physicist Francis Halzen, also of the University of Wisconsin-Madison, the South Pole now ranks with the grand research laboratories such as Fermilab and CERN. Astronomers ideally want somewhere cold, dark, remote and dry. Antarctica, and the South Pole in particular, fit the bill very well, which is why some of the world's leading telescopes are now located less than a mile from the South Pole. Indeed, if you're interested in millimetre-wavelength observations – for viewing far distant space objects – that are generally absorbed by atmospheric moisture, then the only place arguably better than Antarctica for your telescope is in space, which is a tad more inconvenient to reach. The South Pole is therefore an ideal location for astronomers, as the growing number of observational platforms established in the last few decades clearly shows.

It also helps that, while the land at the South Pole is estimated to be around 100 metres (328 feet) above sea level, the ice sheet on top of it adds a further 2,700 meters (9,000 feet). Given that the air we breathe is enough of a distorting barrier to interfere with many astronomical

"One irony of Antarctic astronomy is that sometimes the South Pole just isn't cold enough by itself"

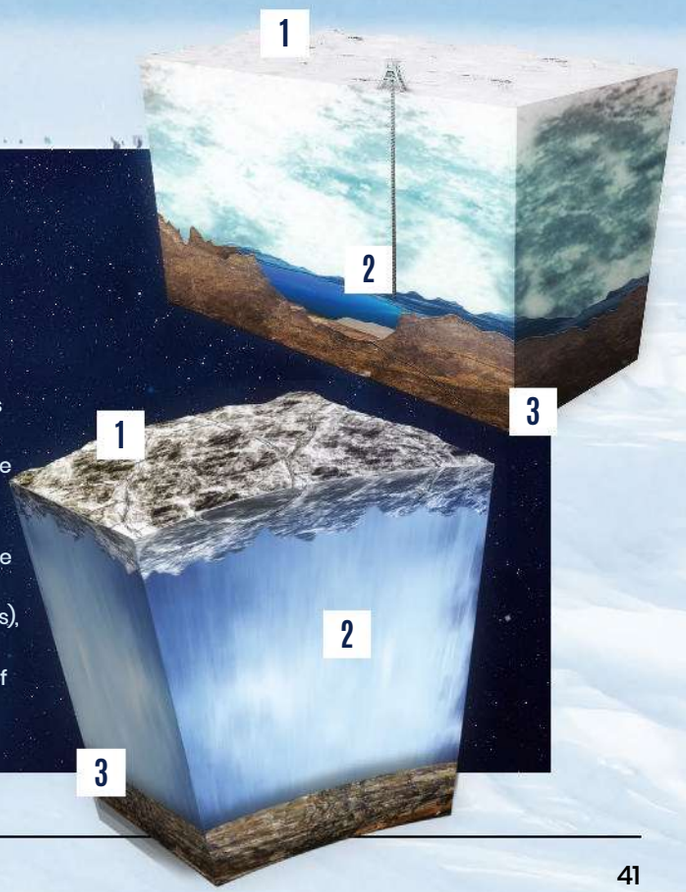
ANTARCTICA VERSUS EUROPA

How this frozen continent compares to the icy crust of Jupiter's moon

1 Frozen surface
The ice covering Lake Vostok is around four kilometres (2.5 miles) thick. That compares with estimates of up to 30 kilometres of ice (19 miles) protecting Europa's oceans.

2 Water world
Lake Vostok remains liquid thanks to geothermal heat and high pressure. The heat for Europa's oceans comes from tidal forces experienced during its speedy orbit around Jupiter.

3 Into the deep
Measurements of Lake Vostok suggest an average depth of 432 metres (1,417 feet). Europa's oceans are estimated at 100 kilometres (60 miles), with more than twice the volume of Earth's oceans.



observations, telescopes located near the South Pole have significantly less atmosphere to look through. The air is also very cold and dry, reducing the atmospheric emission of infrared light, which can interfere with observations. Plus, during the constant darkness experienced in Antarctica throughout the winter months, the relative lack of daily temperature extremes reduces the strength of any distorting air currents in the aurora-filled skies.

Such extreme conditions can push both astronomers and their instruments to their physical limits. The Amundsen-Scott Station near the South Pole is only accessible for a few months each year, when it's warm enough to fly aircraft in and out. This creates necessarily tight windows of opportunity for any telescopes to be assembled, calibrated and started up. Most of the teams involved with these projects will then return home, leaving only a few 'winter-overs' necessary for maintenance during the long night when the Sun doesn't rise above the cool and icy horizon.

Arguably, Antarctica-based astronomy really hit the headlines in March 2014 when a team working at the BICEP2 and Keck Array Experiments, led by John Kovac of the Harvard-Smithsonian Center for Astrophysics, announced that they had successfully detected the much sought B-mode polarisation in the cosmic microwave background (CMB). This, they believed, was direct evidence of the gravitational waves generated during the theorised cosmic inflation, which occurred in the earliest moments of the universe. However, subsequent interpretation of their findings, allied with new data from the European Space Agency's Planck satellite, suggested that this wasn't the case, but that the detected polarisation was, in fact, more likely due to the presence of greater-than-assumed levels of dust in our own galaxy. Nevertheless, the unexpected global interest in the findings of this unique mission proved that the work being carried out at the very bottom of the world is undeniably on the cutting edge of modern-day science.

"The work being carried out at the very bottom of the world is undeniably on the cutting edge of modern-day science"

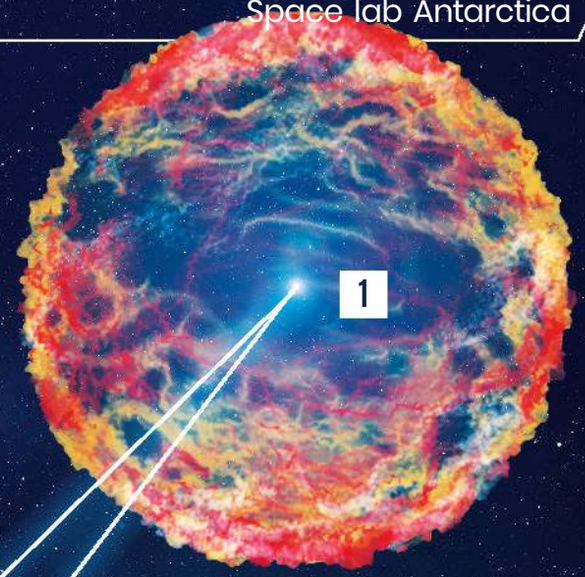
Background Imaging of Cosmic Extragalactic Polarization (BICEP) and the subsequent neighbouring Keck Array were designed specifically to detect the B-mode signature in the CMB, the ancient echo of the Big Bang. BICEP1 operated from the Dark Sector Lab at the Amundsen-Scott South Pole Station, one of three permanent research stations in Antarctica operated by the US' National Science Foundation, between January 2006 and December 2008. A second-generation instrument, BICEP2, featured a significantly greater number of detectors and operated from January 2010 until December 2012. By that time the neighbouring Keck Array, a suite of five telescopes, each duplicating the BICEP2 detector, was fully operational.

BICEP2 has since been replaced by BICEP3, and while retaining the same 2,460 detectors as the Keck Array, it covers much more of the sky. BICEP3 has been designed without the need for an expensive liquid-

The South Pole Telescope (SPT) is the biggest in Antarctica

WHERE DO COSMIC RAYS COME FROM?

These high-energy particles can tell us much about the universe, but how do we detect them?



1 Explosive birth

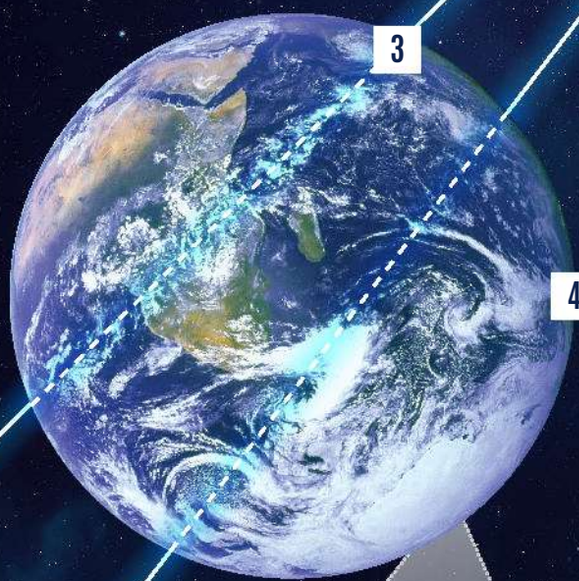
Cosmic rays are high-energy particles released primarily by massive supernova explosions. They include electrically charged particles like protons and electrons and non-electrically charged neutrinos.

2 Journey into space

Travelling through space, the electrically charged cosmic rays will be deflected by the magnetic fields of nearby stars and galaxies. Neutrinos, however, will head on unaffected.

3 Down to Earth

About 100 trillion neutrinos pass through your body every second, but you'd have to wait about 100 years for one to interact with one of your atoms.



4 Gathering the data

About 100 gigabytes of time-stamped data is sent every day from the IceCube Laboratory to a data warehouse at the University of Wisconsin-Madison.

5 Into the detector

IceCube consists of an array of 86 strings of digital optical modules (DOMs) set 125 metres (410 feet) apart. Each has 60 DOMs 17 metres (56 feet) apart.

6 IceTop

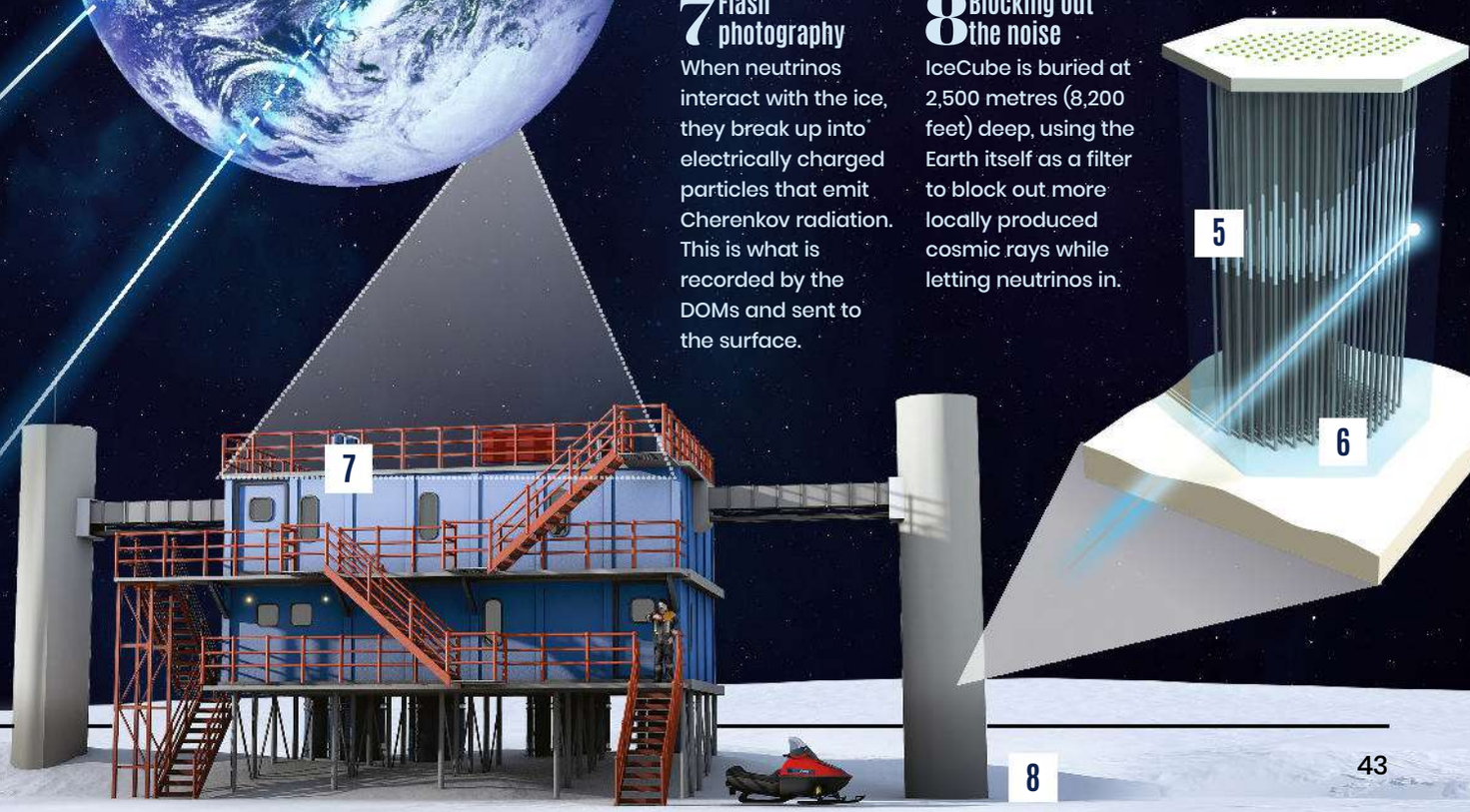
IceTop, built as a 'veto' and calibration detector for IceCube, also measures the cosmic ray arrival directions, as well as their flux and composition.

7 Flash photography

When neutrinos interact with the ice, they break up into electrically charged particles that emit Cherenkov radiation. This is what is recorded by the DOMs and sent to the surface.

8 Blocking out the noise

IceCube is buried at 2,500 metres (8,200 feet) deep, using the Earth itself as a filter to block out more locally produced cosmic rays while letting neutrinos in.



SPACE LAB AT THE SOUTH POLE

A lot of space science is happening in Antarctica

1 ANITA

"To launch a balloon, the surface winds have to be below about eight knots, which is around 14.4 kilometres (9.2 miles) an hour. You also need to have low winds up to about 244 metres (800 feet). The team use a small weather balloon to check those. You'll see it go up, and then all of a sudden it'll take off sideways. When these big stratospheric balloons are launched but not yet fully inflated, they're about 183 metres (600 feet) long. If they hit a heavy wind shear, they can be completely torn apart." **W. Robert Binns, Washington University**

2 Meteorite hunting

"We used our eyes to scan the ice, sometimes with the aid of binoculars. Forming a line, we worked by moving in parallel spaced apart according to the terrain and concentration of meteorites. The fun began when someone waved their arms to signal that the rest of the team needed to converge at the find. A snowmobile with a GPS receiver parked next to the meteorite to record location data and a collection bag was brought out." **Linda Martel, Hawaii Institute of Geophysics and Planetology**

3 South Pole Telescope

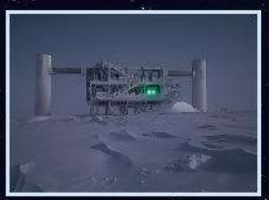
The SPT team installed a bigger, more sensitive camera to further understand how the Solar System formed. "In the next several years, we should be able to get to the sensitivity level where we can measure the number of neutrinos and derive their mass. This will tell us how they contribute to the overall density of the universe. This will enable us to understand even more sensitive constraints on inflation and has the potential to measure the energy scale of the associated physics that caused it." **Bradford Benson, Fermilab**

4 BICEP2

"The South Pole Station is only accessible for about three months out of each year. When we take one of these telescopes like BICEP1 or BICEP2 to the South Pole, we come in with a team and we work furiously for three months to try to get everything to work, put it all together, calibrate it, tune it up and get it in pristine condition. Then all of us get on an aeroplane and leave – except for one guy. He watches the plane go and knows there isn't going to be another one for about nine months." **John Kovac, Harvard University**

5 IceCube

"We embedded more than 5,000 photosensors in the ice to watch for faint flashes of light produced when neutrinos happen to interact with atoms in the ice. I don't know whether neutrinos will ever be useful. Maybe for communications or geological exploration, or because what we learn from them provides new theories. I'm willing to bet whatever it is will connect back in some way to fundamental research being carried out now by someone who has no idea what it may ever be good for." **Tyce DeYoung, Michigan State University**



helium cooling system, used by its predecessors to keep its detectors sufficiently cool. As Kovac has pointed out, one irony of Antarctic astronomy is that sometimes the South Pole just isn't cold enough by itself.

Another telescope located at the South Pole is the aptly named South Pole Telescope (SPT). Constructed in 2006 by a team led by several postdoctoral scientists from the University of Chicago, the ten-metre (33-foot) diameter telescope remains physically the largest telescope ever deployed in Antarctica. This scale was necessary to ensure that the SPT's observations at millimetre and submillimetre wavelengths were both as sharp and as bright as possible.

The SPT's initial project, which began in March 2007, was a wide survey searching for distant clusters of galaxies, based on their distortion of the CMB. When this data was combined with existing information on the galaxies' estimated masses and the speed at which they were moving away from us, the results provided useful clues as to the nature of dark energy, the mysterious theoretical form of energy that's helping push everything in the universe apart. Following the success of this first objective, the new SPTpol camera was installed in 2012. While providing greater sensitivity, a more significant feature was the new sensor's capability of measuring the polarisation of incoming light. This means that the SPT, alongside the neighbouring BICEP instruments and Keck Array, is now being used to search for B-mode components in the polarisation of the CMB.

In July 2013, the SPT team announced they had done so, though this particular polarisation was the result of gravitational lensing of more conventional E-mode CMB polarisation. According to the team, this was a significant development in their cosmological work. "Successfully detecting this minuscule B-mode signal represents a major milestone along the way to using the CMB to learn about the earliest moments of the universe," the team said at the time.

Even at the South Pole, atmospheric interference is still a problem, which is why despite a reputation for having some of the fiercest weather on the planet, Antarctica is a global hotspot for scientific ballooning, including NASA's own Ultra Long Duration Balloon (ULDB) project. Balloons may seem like old technology, but there's plenty of cutting-edge science involved in what remains a remarkably inexpensive way of getting scientific instruments above most of Earth's atmosphere. These 21st-century balloons, designed to offer long-duration flights at stable altitudes, are often massive structures. NASA's heavy-lift super pressure balloon (SPB), for example, is made from some 22 acres of toughened polyethylene film and is big enough to contain an entire football stadium. Plus, it's capable of staying in position for weeks or even months.

Antarctica is particularly good for scientific ballooning for two reasons: firstly because the circumpolar wind is a strong, steady wind high in the stratosphere that carries balloons steadily and predictably around the globe. Secondly, the nightless Antarctic summers minimise the effects of daily heating and cooling that causes balloons to lose altitude over time. There have been many notable balloon-carried projects, including the Advanced Thin Ionization Calorimeter (ATIC), an international collaboration to measure the energy and composition of cosmic rays; the Balloon-borne Experiment with Superconducting Spectrometer (BESS) and a joint US-Japan experiment to detect antimatter particles in cosmic radiation at high altitudes. In addition, NASA funded the Antarctic Impulsive Transient Antenna (ANITA) project, which is studying ultra-high-energy cosmic neutrinos by detecting the radio pulses emitted by their interactions with the Antarctic ice sheet. Three generations of ANITA have so far been launched, the most recent in December 2014, and each is dependent on the circumpolar winds of the Antarctic to propel it around the continent for approximately a month before landing and recovery.

As of January 2023, IceCube has detected over 25 neutrinos with energy signatures from outside the Solar System

The IceCube Neutrino Observatory consists of an array of 5,000 highly sensitive optical sensors, buried sufficiently deep in the ice from 1,450 to 2,450 metres (4,757 to 8,038 feet), to detect the tiny cascade of electromagnetic particles, including Cherenkov radiation, which occurs when neutrinos interact with the ice. "The idea of a detector goes way back to 1960 with Russian Moisey Markov, who had the idea of using a big volume of water. But by the 1980s some people had the idea to use ice, if it was clear enough" explains Hanson. "Because the optical properties of the ice at the South Pole are so favourable, light travels 100 metres (328 feet) and maybe up to 200 metres (656 feet) in the deep ice without getting absorbed. We can place our sensors relatively far apart, and in that manner effectively instrument one square kilometre (0.39 square miles) of target relatively cheaply.

"Ice is even more transparent to radio waves" he adds, "so we started a new line of detectors down there that use radio emission from neutrinos that interact with the ice. We think we can actually get much larger volumes using radio waves. As of January 2023, IceCube has detected over 25 neutrinos with energy signatures from outside the Solar System, with the first two being nicknamed Bert and Ernie. "After we found Bert and Ernie, we had the signal we knew we were looking for, and so we could go back and do a follow-up analysis of the data," Hanson says. "From the first two years

worth of data, we found several more events that we think were coming from the same general phenomena. The neutrinos are now beginning to come out all over the place."

There's more than you might think underneath the Antarctic ice, not least an estimated 400 subglacial lakes. The largest and best known is Lake Vostok, named after the Russian research station that sits above its southern tip. Approximately 250 kilometres (155 miles) long and 50 kilometres (31 miles) at its widest point, Lake Vostok covers a staggering 12,500 square kilometres (4,826 square miles). It has been isolated from the rest of the world by about four kilometres (2.5 miles) of ice for an estimated 15 million years.

Almost from when Lake Vostok's existence was first confirmed in the early 1990s, astrobiologists have been speculating about what extreme alien ecosystem the lake could contain, given that evolution has had 15 million years to do its own thing in the dark. There are potential parallels with the subsurface ocean that many believe exists on Jupiter's moon Europa. If life can be found in Lake Vostok, then why not on Europa?

Despite criticisms and pleas from the likes of the United States National Research Council and the Antarctic and Southern Ocean Coalition (ASOC), Russian scientists have instigated several attempts to drill down to the mysterious depths of the lake. Relying largely on techniques that use chemicals like Freon and kerosene to lubricate the borehole, there have been some fears that any recovered samples and the lake itself could be irretrievably contaminated, damaging the current ecosystem. The first core of freshly frozen lake ice was obtained on 10 January 2013, which Russian scientists say included DNA unlike any known bacteria. A second borehole was completed in January 2015. Whatever the results, it's clear that a wide variety of technical, procedural and ethical issues will still be hotly discussed for years to come and are likely to shape any future exploration of locations such as Europa.

Astronomy in Antarctica began on 5 December 1912, when Frank Bickerton, a member of Douglas Mawson's Australasian Antarctic Expedition, happened to pick up part of a meteorite that was soon termed the Adelie Land Meteorite (ALM). Weighing just about a kilogram, the ALM was eventually classified as an ordinary chondrite and would be just the first of many thousands of new discoveries to be made in Antarctica. Antarctica is now the richest source of meteorites in the world.

While meteorites fall randomly all around the planet, it's easier to spot them against a plain background with a minimal accumulation of indigenous sediments. The East Antarctic Ice Sheet is a perfect hunting ground for any meteorite hunter, and most rocks on the ground will have come from the sky. As the East Antarctic Ice Sheet flows towards the edge of the continent, it's occasionally blocked by mountains or subsurface obstructions. These obstructions push meteorites trapped in old, deep ice to particular areas of the surface, where the elements blow away the snow and ice.

With human attention turning once again to the Moon and Mars, it's very useful to remember that a lot of what we have learned about our nearest astronomical neighbours wasn't achieved by going there, but by examining fragments that had been blasted off them. Subsequently, we have discovered these fascinating objects as we search the freezing Antarctic landscape. Possibly the largest such program is the US Antarctic Search for Meteorites (ANSMET), which by 2012 had collected more than 20,000 meteorites. Parallel programs have been run by other nations, providing much of the extraterrestrial materials now available for scientific study around the world.

Paul Cockburn
Space science writer
Paul has been writing about and keeping up to date with the latest research in science, technology and space for more than 25 years.

Members of the SPT team

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INSTANT EXPERT

HOW THE PLANETS WOULD LOOK...

...if they were at the same distance from Earth as the Moon, and how it would affect our planet

What if the other Solar System planets were the same distance from Earth as the Moon? At best, a night sky with one or more planets at the Moon's distance would look very different. At worst, either the other planet or Earth – or both – would be radically changed by its proximity to the other. In some cases, we wouldn't survive. There are numerous factors involved, but speculation is part of the fun of astronomy.

Mercury, the closest planet to the Sun, is also a similar size to our Moon, with a radius of 2,439.7 kilometres (1,516 miles). It has similar surface features to the Moon from a

1 Mercury

Mercury is approximately 4.5 times more massive than the Moon. This would no doubt affect the tides on Earth. It also has a magnetic field that could affect Earth's.

3 Venus

Venus in its current state has a very dense, toxic atmosphere, with a surface that can't be easily viewed. If it were closer, though, Earth's magnetic pull might affect that atmosphere, and vice versa.

4 Mars

If Mars were as close as our Moon, travelling there would be much simpler. We could see many of its unique features with the naked eye, and maybe a Martian colony wouldn't be out of the question.

5 Jupiter

It's unlikely that we'd survive if Jupiter became our Moon. It would blast us with its deadly radiation field and subject Earth to incredibly strong tidal stresses.

2 The Moon

With a radius of 1,737.4 kilometres (1,079.6 miles), our Moon takes up about as much sky as the Sun, which is how they can appear to be the same size and distance away.

BIO
ROBIN HAGUE
Robin is a science writer, focusing on space and physics. He is the current head of launch at Skyrora, coordinating launch opportunities for Skyrora's vehicles and liaising with UK launch regulators.

distance, although if it were close up we'd be able to see that the craters, rays and other features are quite different.

Venus has a radius of 6,051.8 kilometres (3,760.4 miles) and would look as large to us as planet Earth looked to the Apollo astronauts when they were walking on the Moon. It reflects six times the amount of sunlight that the Moon does and would take up about 12 times the space in the sky from our perspective, so 'night', when Venus is on the opposite side of the sky from the Sun, would be much brighter.

Mars is about twice the size of the Moon, with a radius of 3,389.5 kilometres (2,106 miles), so it would look larger than the Sun does to us. Having Mars or any other planet larger than our Moon for a satellite would have an effect on the tides, causing huge waves and even tsunamis. Beach-going would probably be a thing of the past, but we'd have more light at night, and it would have a creepy red tint to it.

Jupiter would completely dominate our sky. Astronomers measure the distances between objects in the sky using degrees – our Moon takes up about half a degree, but Jupiter would take up 20 degrees. We wouldn't be able to see Jupiter's poles, but we would be treated to a view of its distinctive caramel-and-white bands and the ongoing storms on the planet. Saturn has a radius that's more than nine times that of Earth's, and in truth Earth would really become a satellite of Saturn instead.

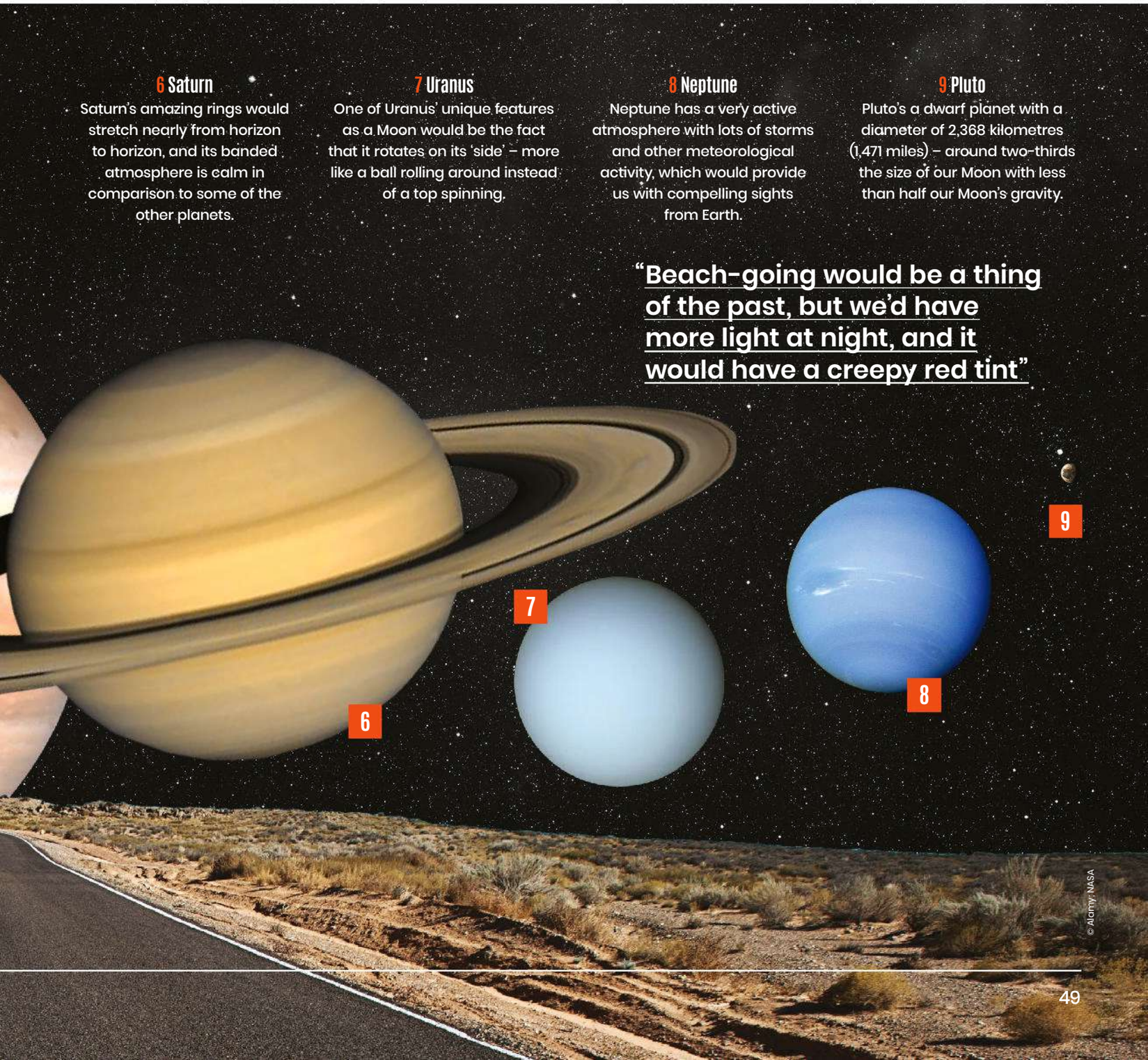
Although not as huge as Jupiter or Saturn, Neptune is still 14 times larger than the Moon. This big, blue planet would still dominate the sky at all times. There's a reason why Neptune and Uranus are sometimes called sister planets: both are icy worlds and have a radius about four times that of Earth's, although Uranus has a much calmer atmosphere than the other turbulent giant planets.

6 Saturn
Saturn's amazing rings would stretch nearly from horizon to horizon, and its banded atmosphere is calm in comparison to some of the other planets.

7 Uranus
One of Uranus' unique features as a Moon would be the fact that it rotates on its 'side' – more like a ball rolling around instead of a top spinning.

8 Neptune
Neptune has a very active atmosphere with lots of storms and other meteorological activity, which would provide us with compelling sights from Earth.

9 Pluto
Pluto's a dwarf planet with a diameter of 2,368 kilometres (1,471 miles) – around two-thirds the size of our Moon with less than half our Moon's gravity.



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EXTREME STARS

From the biggest and brightest to the smallest and dimmest, we take a look at some stellar extremes

Written by Andrew May

The Sun produces heat and light through nuclear fusion, converting hydrogen into helium. In this respect, it's a pretty typical star. Around 90 per cent of all stars are undergoing the same process, referred to as the main sequence of the stellar life cycle. Even so, there are some striking exceptions, such as stars of very low or very high mass or ones that have exhausted all their nuclear fuel. Here we take a look at some of these extreme stars – from brown dwarfs to supergiants and from neutron stars to weird hybrid stars. But first it's worth reviewing the basics of stellar evolution.

Although the stars in the night sky look similar to the naked eye, there's actually a wide variety of stellar types. This is partly because we see different stars at different points in their evolutionary cycles. This proceeds much too slowly for us to observe directly, so each star is like a single snapshot along the evolutionary path. It begins in a cloud of interstellar gas, where knots can form with sufficient mass that they start to collapse under their own gravity. As the collapse proceeds, the material gets hotter and denser, eventually forming protostars. Not all protostars are equal, even those formed in the same interstellar cloud at the same time. They come in a wide range of masses, from much smaller than our own Sun to many times larger. What happens next depends on the mass of the protostar. All but the very lowest mass stars soon become hot enough for nuclear fusion to take place, putting them on the main sequence. Somewhat paradoxically, however, it's the high-mass stars that burn through their nuclear fuel most rapidly before moving on to the later – and often much more dramatic – phases of stellar evolution.

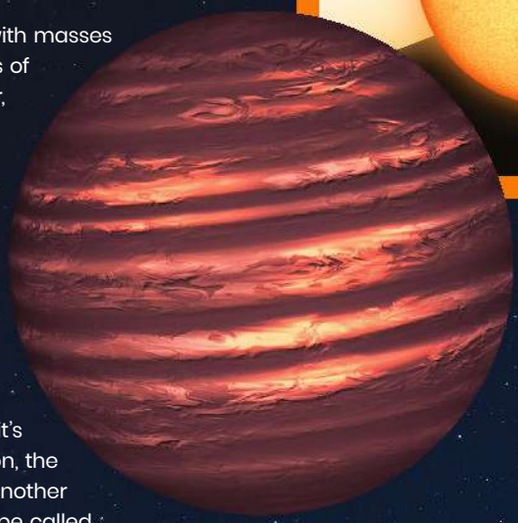
Two supergiants make up Orion: Betelgeuse at the top (red) and Rigel at the bottom (blue)

© NASA / ESA / Getty

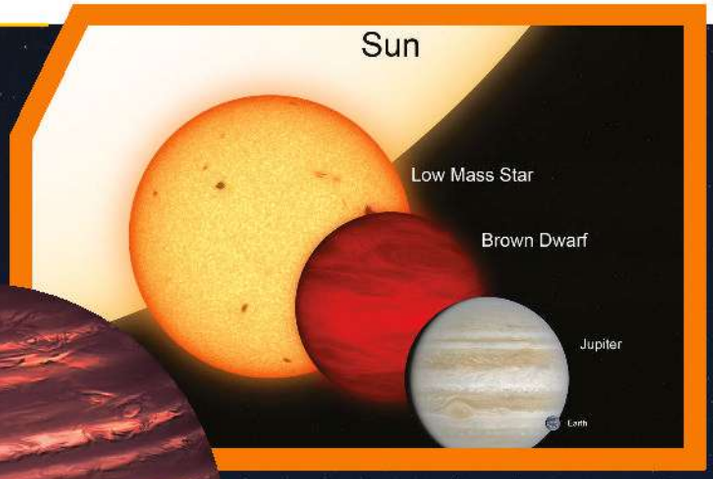
BROWN DWARFS

Shining only very dimly, these low-mass objects are sometimes classed as failed stars

Brown dwarfs are the smallest stars, with masses in the range of 15 to 75 times the mass of the planet Jupiter. Like an ordinary star, a brown dwarf starts life by collapsing under its own gravity from a cloud of interstellar gas, but it doesn't have enough mass for the core temperature to rise to the point where hydrogen undergoes nuclear fusion. In other words, it never reaches the main sequence phase of stellar evolution. So why is a brown dwarf a star and not simply a very large planet? The reason is that while it's insufficient for ordinary hydrogen fusion, the core temperature is high enough for another kind of fusion involving a scarcer isotope called deuterium. This means the brown dwarf shines, albeit very dimly, with its own light – something a planet can't do. Even after all the deuterium is used up, the brown dwarf's retained heat means that it still radiates more energy than a planet. As it slowly cools down, this radiation declines from reddish light similar to a more conventional hydrogen-burning red dwarf star to very dim infrared light that is only barely perceptible, even with a powerful telescope.



As this artist's conception shows, brown dwarfs may look more like planets than stars



Comparative sizes of the Sun, a red dwarf, a brown dwarf, Jupiter and Earth

Brown dwarf

Star mass:
0.01 to 0.08 solar masses
Star diameter:
0.06 to 0.12 solar diameters
Star lifetime:
Trillions of years

BLUE SUPERGIANTS

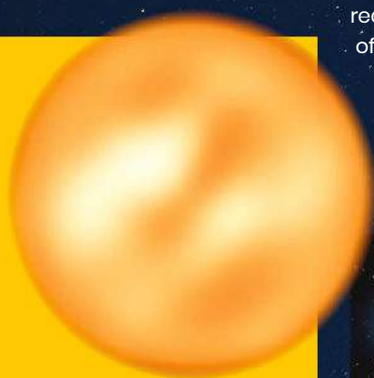
These are extremely massive young stars that have already used up most of their hydrogen fuel and are now fusing helium into heavier elements. Despite their size and luminosity, they're actually very rare, accounting for less than one in a thousand of the stars in the galaxy. There are two reasons for this. To start with, when clusters of stars form in interstellar gas clouds, the distribution of masses is strongly biased towards low-mass stars. Secondly, high-mass stars have very short life spans – only about 10 million years compared to 10 billion or more for our Sun.

Blue supergiants are easiest to find in young star clusters like this one

SUPERGIANT STARS

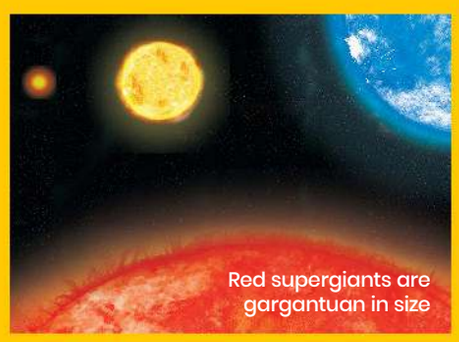
The brightest stars in the galaxy live fast and die young

These stars are classified according to two main parameters: intrinsic luminosity and colour. In these terms, a supergiant is simply any star that lies at the upper end of the luminosity range. But there's actually quite a difference between blue and red supergiants. A blue supergiant is a comparatively young star that's so incredibly massive that it burns through all its hydrogen – and hence exits the main sequence – after just a few million years. On the other hand, a red supergiant is a star of somewhat lower mass, though still more than ten times that of our Sun, that's nearing the end of its life. After passing through the red giant phase of its evolution, it begins a final phase of carbon-forming nuclear fusion, causing it to expand to truly enormous dimensions.



Supergiant

Star mass:
Over ten solar masses
Star diameter:
30 to 500 solar diameters
Star lifetime:
10 million years



Red supergiants are gargantuan in size

NEUTRON STARS

The densest stars of all are more massive than the Sun, but only miles across

Normal atoms are composed of electrons, protons and neutrons, but if they're squashed together forcefully enough then the protons and electrons combine to form further neutrons, and eventually that's all that's left. The result is one of the most extreme forms of matter known to science, and it's what neutron stars are made of. A neutron star is one of the possible outcomes when a star finally runs out of nuclear fuel and collapses under its own gravity. Small and medium-sized stars like the Sun end up as white dwarfs, while the most massive stars become black holes. In between the two, the end result is a neutron star – an object more massive than the Sun but compressed down into a volume the size of a city. Under normal circumstances it would be virtually impossible to observe a neutron star. But fortunately for astronomers, some of them give their presence away in a highly dramatic form as a pulsar. These are rapidly spinning neutron stars with strong magnetic fields which emit high-energy beams that can be detected as regular flashes of radiation when they periodically point towards Earth.

A NASA visualisation of a pulsar showing its magnetic field lines and emitted light beams

Neutron star

Star mass:
1.4 to 3.2 solar masses
Star diameter:
9.9 to 29.9 kilometres (6.2 to 18.6 miles)
Star lifetime:
Billions of years

The birth of a neutron star

1 Massive star
For stars in this class, the final stages of main sequence evolution produce an iron-rich inner core.

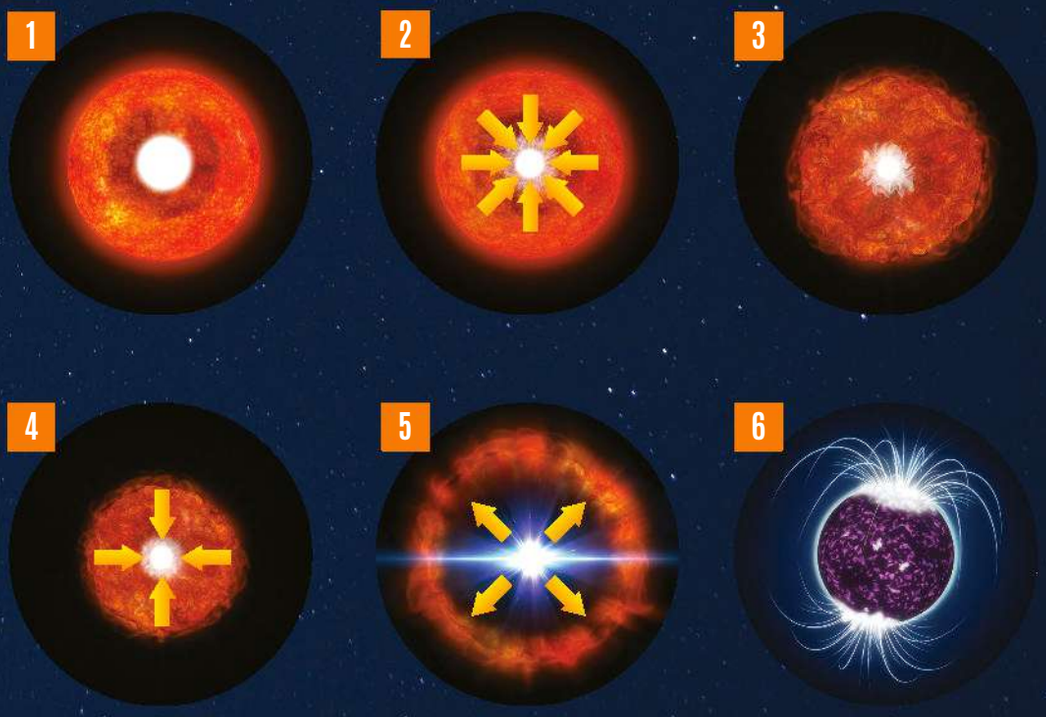
2 Core collapse
When all the nuclear fuel has been used up, the dense core collapses under its own gravity.

3 Neutron formation
As gravity compresses the atoms in the core, electrons and protons are squashed together to form neutrons.

4 Outer layer collapse
The star's outer layers also start to collapse, falling into the core at a quarter of the speed of light.

5 Supernova explosion
The energy generated by the collapsing core blows off the outer layers in a spectacular supernova explosion.

6 Neutron star
All that remains is the incredibly dense core, composed almost entirely of neutrons.



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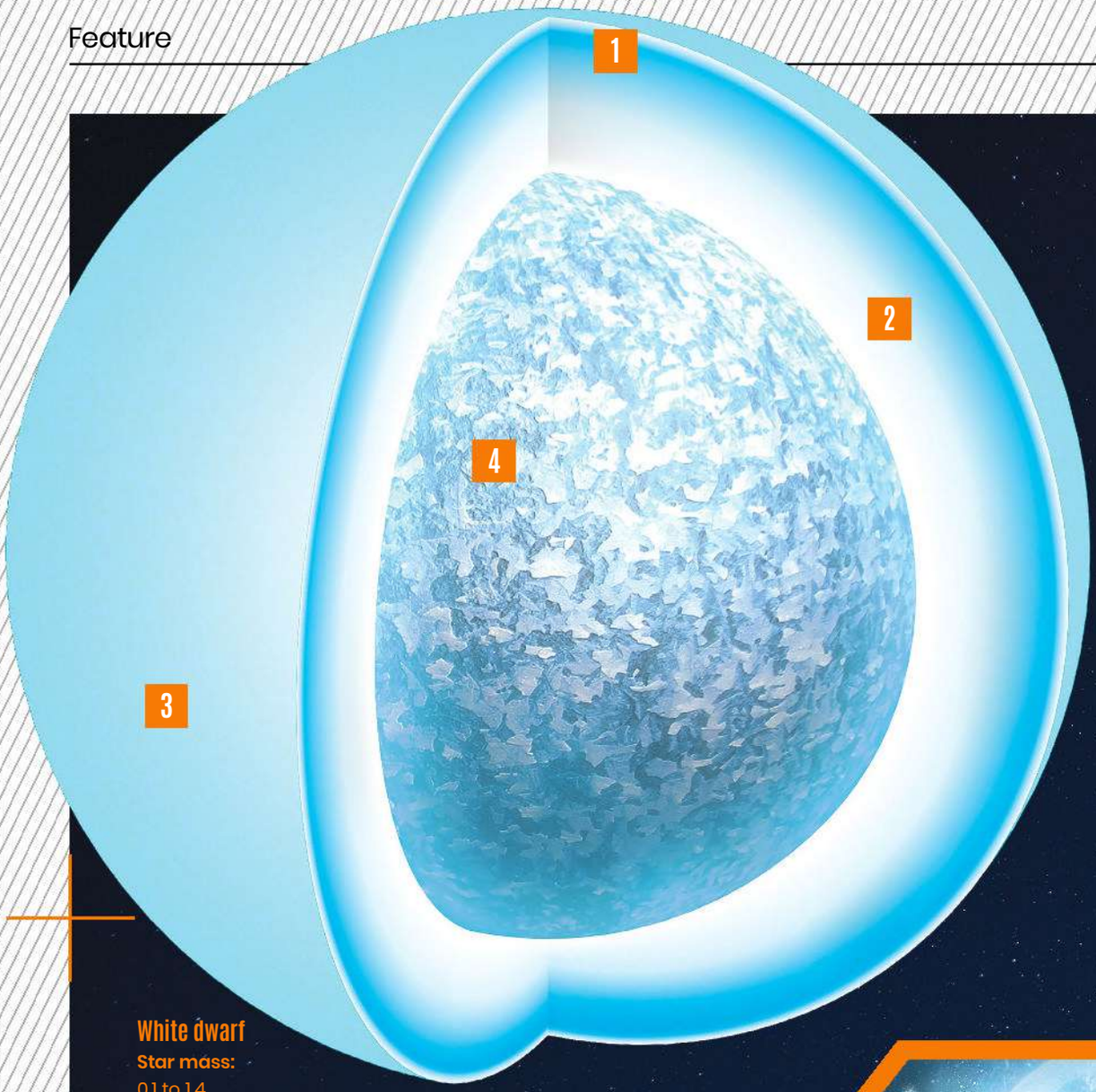


Inside a white dwarf

1 Hydrogen shell
A residual amount of hydrogen that hasn't been consumed by nuclear fusion makes up the outermost layer.

2 Helium shell
Outside the carbon-oxygen core are two much thinner layers, the inner of which is composed of helium.

3 Surface gravity
A white dwarf is so dense that the gravitational force on its surface is 350,000 times stronger than on Earth.

4 Core
Containing the bulk of the star's mass, this is a densely packed crystalline sphere consisting mainly of carbon and oxygen.

White dwarf

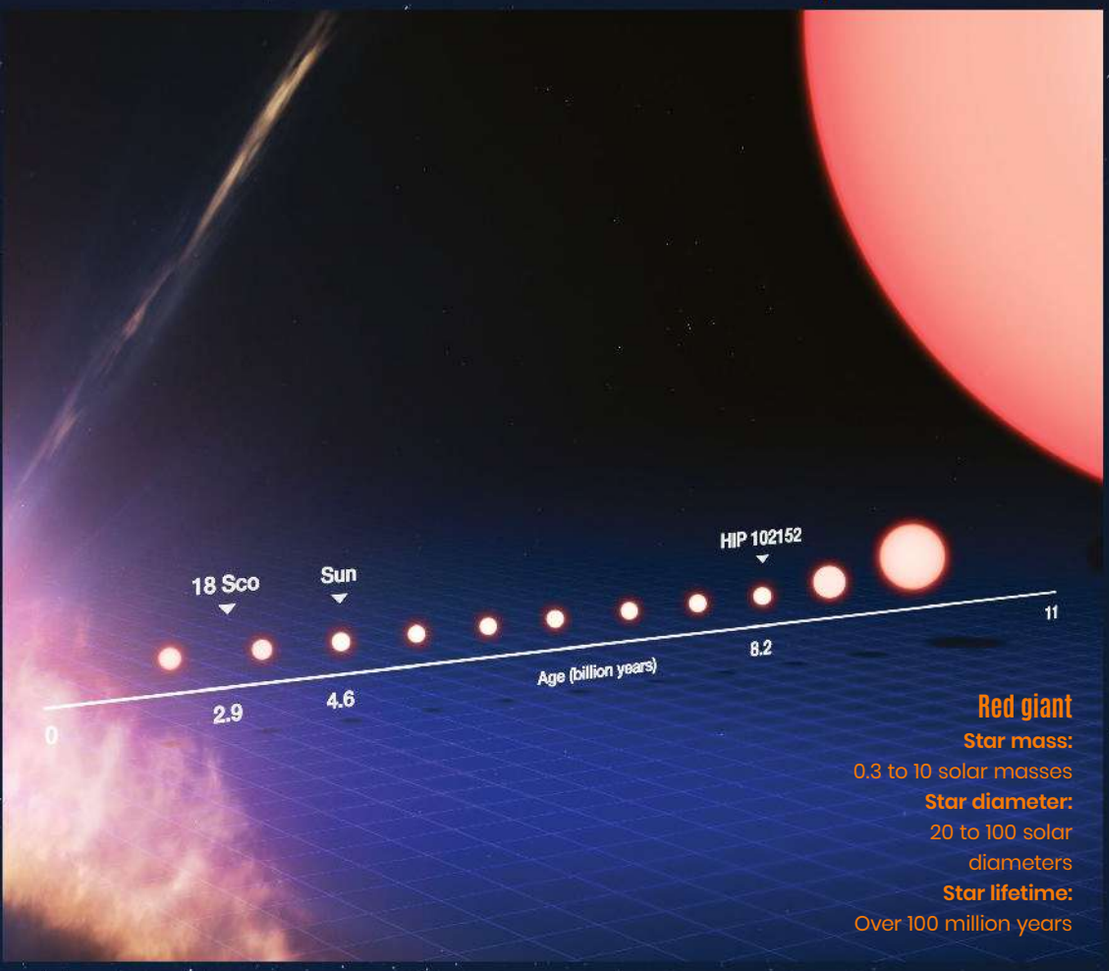
Star mass:
0.1 to 1.4 solar masses
Star diameter:
Around one Earth diameter
Star lifetime:
Billions of years

WHITE DWARFS

The surprisingly extreme fate of an ordinary star like the Sun

Artist's impression of a newly collapsed, superdense and very hot white dwarf star

A white dwarf represents the final stage in the evolution of a star like the Sun, following on from the comparatively brief red giant phase. During the previous phase, the core of the star was gradually shrinking and getting hotter while the outer layers expanded to enormous proportions. Eventually the core generates so much energy that it blows the outer layers off completely, leaving just the dense, hot core behind. This core is the white dwarf, which will continue to exist, gradually losing its accumulated heat, for many billions of years. Although a white dwarf is extremely dense by ordinary standards, it's not as dense as a neutron star, where all the matter has been compressed down to neutrons. While a neutron star packs all of a star's mass into a volume just a few miles across, a white dwarf is around the same size as Earth. It's still composed of atomic nuclei and electrons like ordinary matter, but squashed down to the point where the separation between electrons is comparable to their wavelength. This produces a phenomenon called degeneracy pressure, supporting the white dwarf against any further collapse.



Red giant
Star mass: 0.3 to 10 solar masses
Star diameter: 20 to 100 solar diameters
Star lifetime: Over 100 million years

RED GIANTS

A dramatic phase of stellar evolution that lies in the Sun's own future

Most of the extreme stars we've listed here differ from our Sun in that they started out with lower masses, like brown dwarfs, or higher masses, like supergiants and neutron stars. The Sun's evolution will never take it in any of those directions. On the other hand, there are two extreme phases of the stellar life cycle that do lie in the Sun's own future: the red giant phase and the white dwarf phase. Currently the Sun is on the main sequence, converting hydrogen into helium via nuclear fusion. This phase is expected to end in about 5 billion years, after which the Sun will expand into a red giant so huge that it engulfs the planets Mercury and Venus – and possibly even Earth. The energy for this expansion, which is of the star's outer layers only, actually comes from a contraction as the core shrinks down and heats up.

A STAR WITHIN A STAR?

We speak to astrophysicist Cole Miller about hypothetical hybrid stars known as Thorne–Żytkow objects

What is a Thorne-Żytkow object?
A hypothetical object in which a red giant or supergiant with a radius on the order of the Earth-Sun distance contains a neutron star in its core. Neutron stars and regular stars can orbit each other, and the suggestion is that when the regular star evolves into the red giant phase it might sometimes swallow the neutron star.

What's the history behind this strange stellar idea?
An early suggestion was by the great Soviet physicist Lev Landau, who proposed in 1938 that a small neutron star core at the centre of normal stars could provide their power sources. That turns out not to work, but in 1977 Kip Thorne and Anna Żytkow of the California Institute of Technology made the suggestion that bears their names. Landau hoped that the idea would be amazing enough to save him from arrest as a dissident in Stalinist Russia, but it didn't work and he spent a year in prison.

Are these objects purely theoretical, or have they actually been observed?
The evidence isn't clear because differences from standard red giant stars are subtle. As Thorne and Żytkow noted, such stars "are thoroughly hidden from the prying eyes of the astronomer by the huge, tenuous red-giant envelope". It could be that the abundances of certain isotopes would be different than normal in such stars. There was a report in 2014 that a star named HV 2112 has anomalous abundances of the element rubidium and the expected very high luminosity – about 100,000 times that of the Sun. However, in 2018 a reanalysis by another group found a lower luminosity and no excess of rubidium. At the same time, the 2018 paper proposed its own stellar candidate, HV 11417, so there is still hope.

Miller is a professor of astronomy at the University of Maryland

© Getty / European Southern Observatory / Cole Miller

Falling down a BLACK HOLE and ten other space experiences

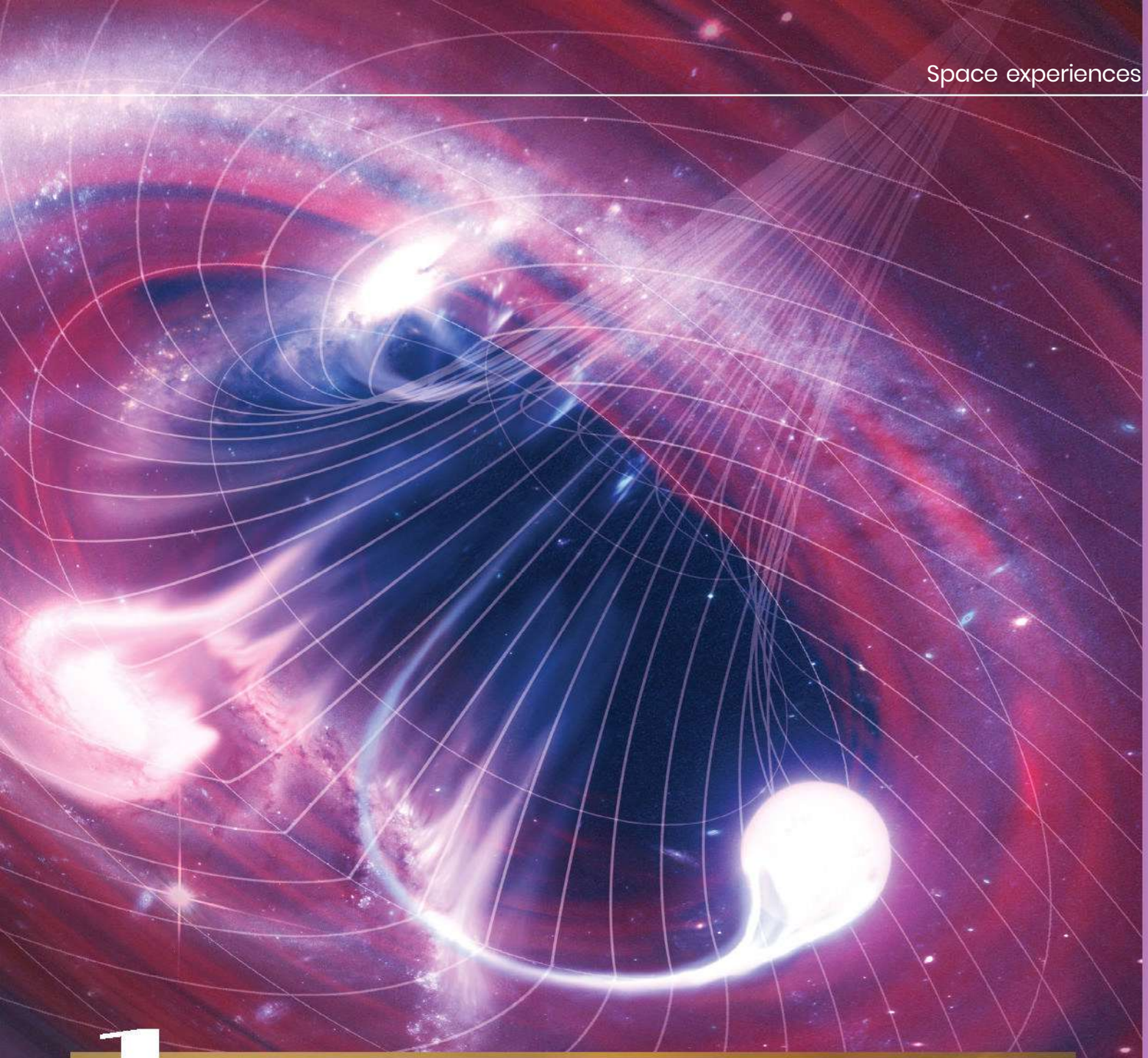
What would it feel like to visit some of the strangest places in space?

Written by Laura Mears

Black holes are some of the most feared objects in the universe, and falling into one might seem like the stuff of nightmares, but the reality might be less traumatising than you imagine.

If you came too close to a small black hole you would be torn apart before you even reached the event horizon, as tidal forces would stretch your body like spaghetti. However, if you circled a bigger black hole, like the one at the centre of the Milky Way, you'd be able to get right into the action. With the most massive black holes, the tidal forces outside of the event horizon are lessened, so you would be able to enter unharmed. However, as you cross over this horizon, the laws of physics go a bit wrong. To an outside observer you would appear to stretch as you approached it, and when you finally reached the edge you would stop, getting redder and dimmer. But from your point of view, you'd still be falling.

Inside the black hole, time dilates. You would be on a one-way trip towards the centre – a point known as the singularity – but it would take a while to get there. Before you arrived there, you might have time to take in the sights, looking at the things that had fallen in before you and the things coming in behind.



1 LIVING ON A TWO-STAR WORLD

The idea of a world with two stars will be familiar to *Star Wars* fans, but it's more than just science fiction. While we orbit a lone star, a lot of the stars that we can see come in pairs. In these 'binary systems', the stars are close enough that their gravitational fields interact, and they orbit together around a point called their common centre of mass, which usually sits somewhere in between them. It wasn't always clear whether it was possible for a planet like Tatooine to exist around a pair of stars, but that all changed in 2011 when NASA announced the discovery of Kepler-16b, a Saturn-sized gas giant orbiting two stars, one red and one orange.

If you could stand on the surface, despite it being a gas world, you would look up into the sky and see two spheres of light – the orange one three times larger and 100 times brighter than the red. These two stars are closer together than the Sun and Mercury and would appear next to one another in the sky. Sunsets would be stunning, changing from day to day as the stars orbit one another in the distance, and occasionally there would be an eclipse that would produce a ring of orange light.

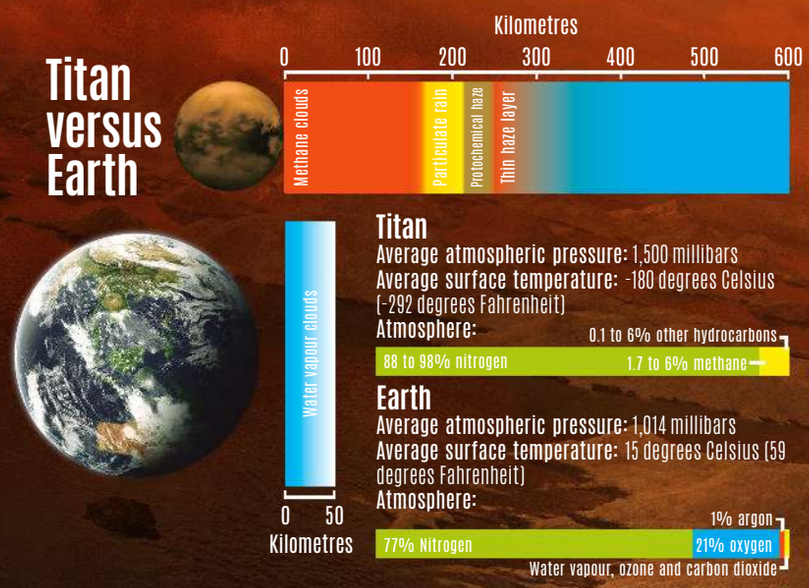
2 FLYING ON TITAN

On Earth, the ability to fly is superhuman, purely the stuff of science fiction, but there are places in space where it might just be possible for humans to fly. One of the closest candidates is Saturn's largest moon, Titan.

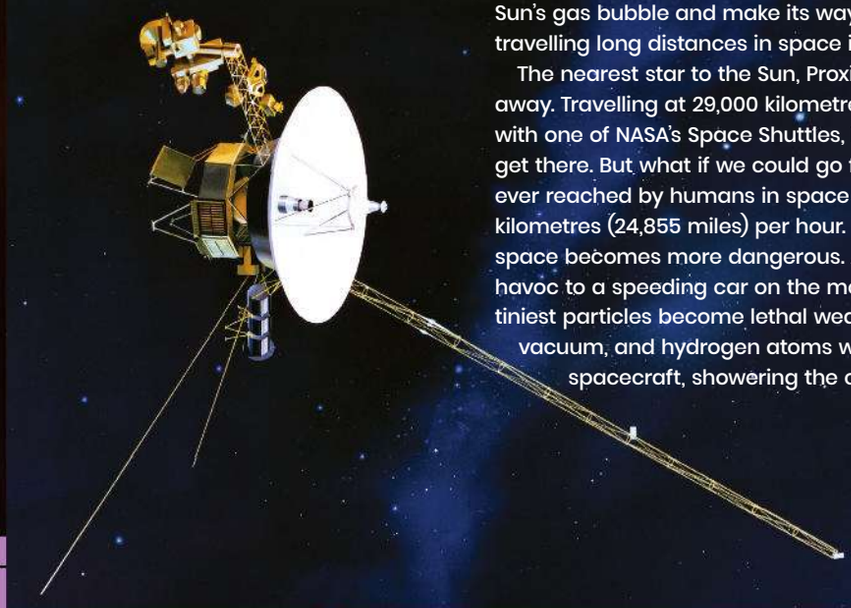
Titan is the only moon in the Solar System with a proper atmosphere. Like our own, it's mostly nitrogen, but instead of oxygen and carbon dioxide, Titan has methane, ammonia, argon and even ethanol. The planet is much less massive than our own, but its atmosphere is 1.5 times thicker, and the combination makes for almost-perfect human flying conditions.

On Earth, we struggle to fly because we cannot generate enough lift, but on Titan there would be less gravity weighing us down and more air molecules to push against. Students at the University of Leicester worked out that, under these strange conditions, a person wearing a wingsuit could fly like a bird.

To use a normal wingsuit you would need a very good run up to get into the air, reaching speeds normally reserved for elite athletes, but with larger wings it would even be possible for an average runner to become airborne on Titan.



3 INTERSTELLAR TRAVEL



There are currently five spacecraft on their way out of the Solar System – Pioneer 10, Pioneer 11, Voyager 1, Voyager 2 and New Horizons. The first four set off in the 1970s, and it wasn't until 2013 that Voyager 1 became the first human-made object to leave the Sun's gas bubble and make its way out into interstellar space. But travelling long distances in space is slow.

The nearest star to the Sun, Proxima Centauri, is 4.2 light years away. Travelling at 29,000 kilometres (18,020 miles) per hour with one of NASA's Space Shuttles, it would take 160,000 years to get there. But what if we could go faster? The maximum speed ever reached by humans in space was by Apollo 10 at 40,000 kilometres (24,855 miles) per hour. But as speeds increase, space becomes more dangerous. A stray pebble can cause havoc to a speeding car on the motorway, so in space even the tiniest particles become lethal weapons. Space isn't a perfect vacuum, and hydrogen atoms would crash into the surface of spacecraft, showering the craft with radiation.

4 DIVING EUROPA'S OCEANS

Jupiter's moon Europa looks like a solid ball of ice from the outside, but beneath the cracked surface is a liquid ocean. Though it's far from the warming rays of the Sun, as the moon orbits its massive parent planet, tidal forces melt the interior. This hidden ocean is one of the best local candidates for extraterrestrial life.

Diving in Europa's oceans would be the trip of a lifetime, but actually reaching the water would be a challenge. On the surface of the moon, the temperature tops out at an icy -130 degrees Celsius (-202 degrees Fahrenheit) and plunges to less than -223 degrees Celsius (-370 degrees Fahrenheit). Though there is liquid beneath the icy surface, Europa's oceans are completely covered in a hard, frozen shell that's estimated to be more than ten kilometres (6.2 miles) thick.

Scientists expect that drilling a hole through the layer of ice would reveal a briny ocean containing particles of rock that have dissolved into the water from the hard core at the centre of the moon. A trip to the bottom could even reveal hydrothermal vents. The water is tens or even hundreds of kilometres deep, and with such a thick, icy covering, no sunlight would be able to penetrate the surface of Europa. Explorers hoping to spot signs of life would need to take a torch.

5 HOT-AIR BALLOONING ON VENUS

The surface of Venus is no place for a human. The atmosphere is mostly carbon dioxide, creating a runaway greenhouse effect that has heated the surface to temperatures hot enough to melt lead. The ground is littered with active volcanoes, the atmosphere is dense enough to crush your bones and clouds of skin-sizzling sulphuric acid hang in the air.

Higher up, however, conditions are better. About 50 kilometres (31 miles) above the surface, the temperatures are closer to a warm spring day back on Earth, and a hot-air balloon could provide the perfect mode of transport for a space tourist.

Unfortunately, the view down to the surface below would be obscured by gas and clouds, and there would be little choice about the direction of travel. The winds in the upper part of Venus' atmosphere are very strong, reaching speeds of up to 400 kilometres (250 miles) per hour. The gravity also varies depending on the terrain, which could cause the balloon to bob up and down as it's buffeted by the weather.

It might not be the smoothest of rides, and the consequences of a balloon puncture would be catastrophic, but it would be a good way of exploring Earth's inhospitable twin without having to descend to the surface.

6 SURFING THE SOLAR WIND

Windsurfing is a popular sport here on Earth, but our atmosphere isn't the only one with a breeze. For a real adventurer and sport extremist, there are more exciting places to set sail. Believe it or not, we are sitting inside the Sun's atmosphere. The ball of light that we see in the sky is just the beginning – the very outer layer of the Sun's atmosphere, the corona, stretches out far beyond Pluto.

Surfers on Earth typically aim to catch winds of between 7 and 18 knots – that's 13 to 33 kilometres per hour, or 8 to 21 miles per hour – using the movement of air particles over the curved sail to generate the pressure differences needed to propel them forwards.

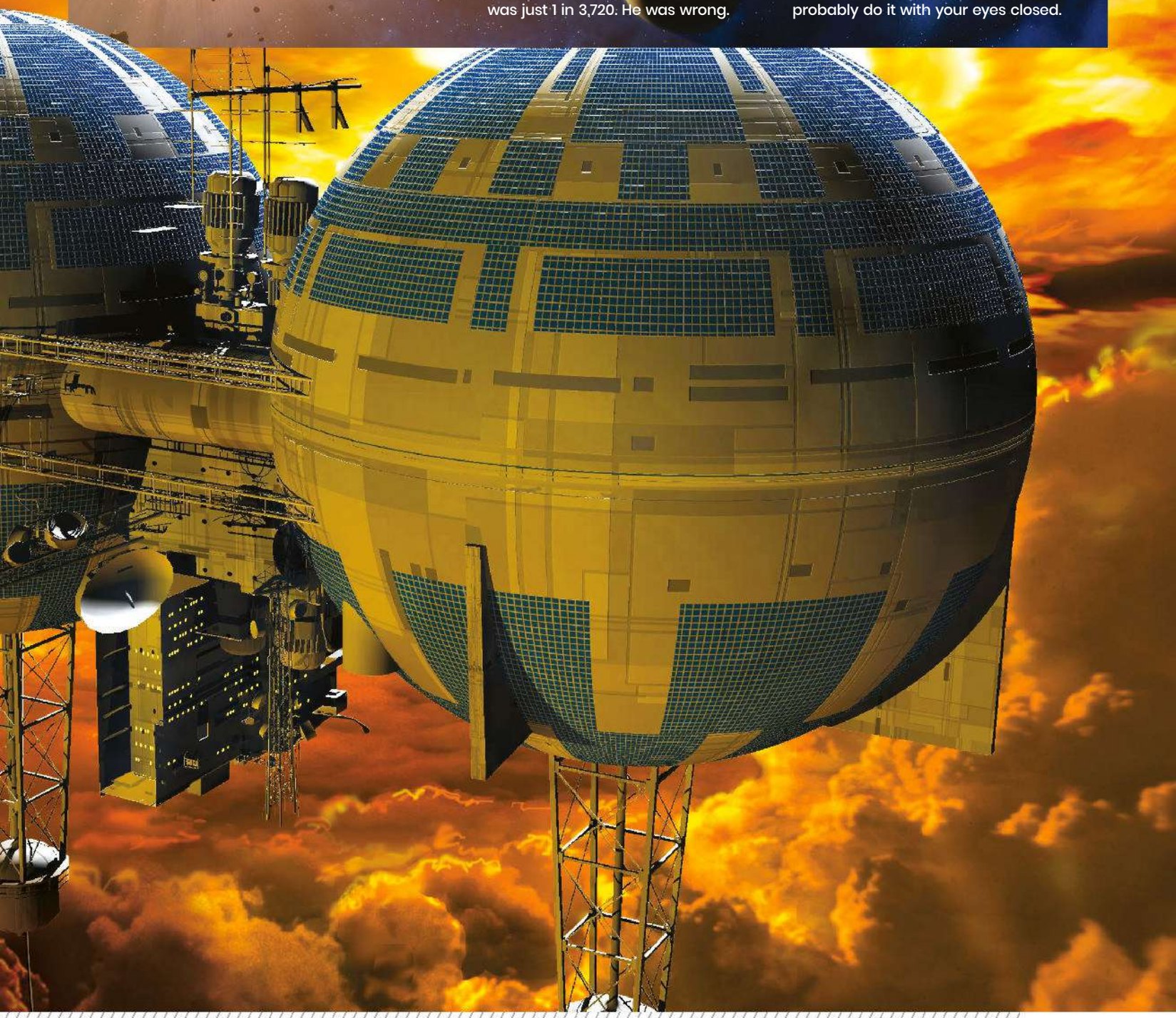
The solar wind reaches speeds of 24,000 kilometres (14,913 miles) per hour, and instead of being driven by the movement of gas, it's the movement of photons of light. Photons do not have any mass, but when they bounce off a reflective surface, they pass on some of their momentum – with a big enough sail, you would gradually start to pick up speed.

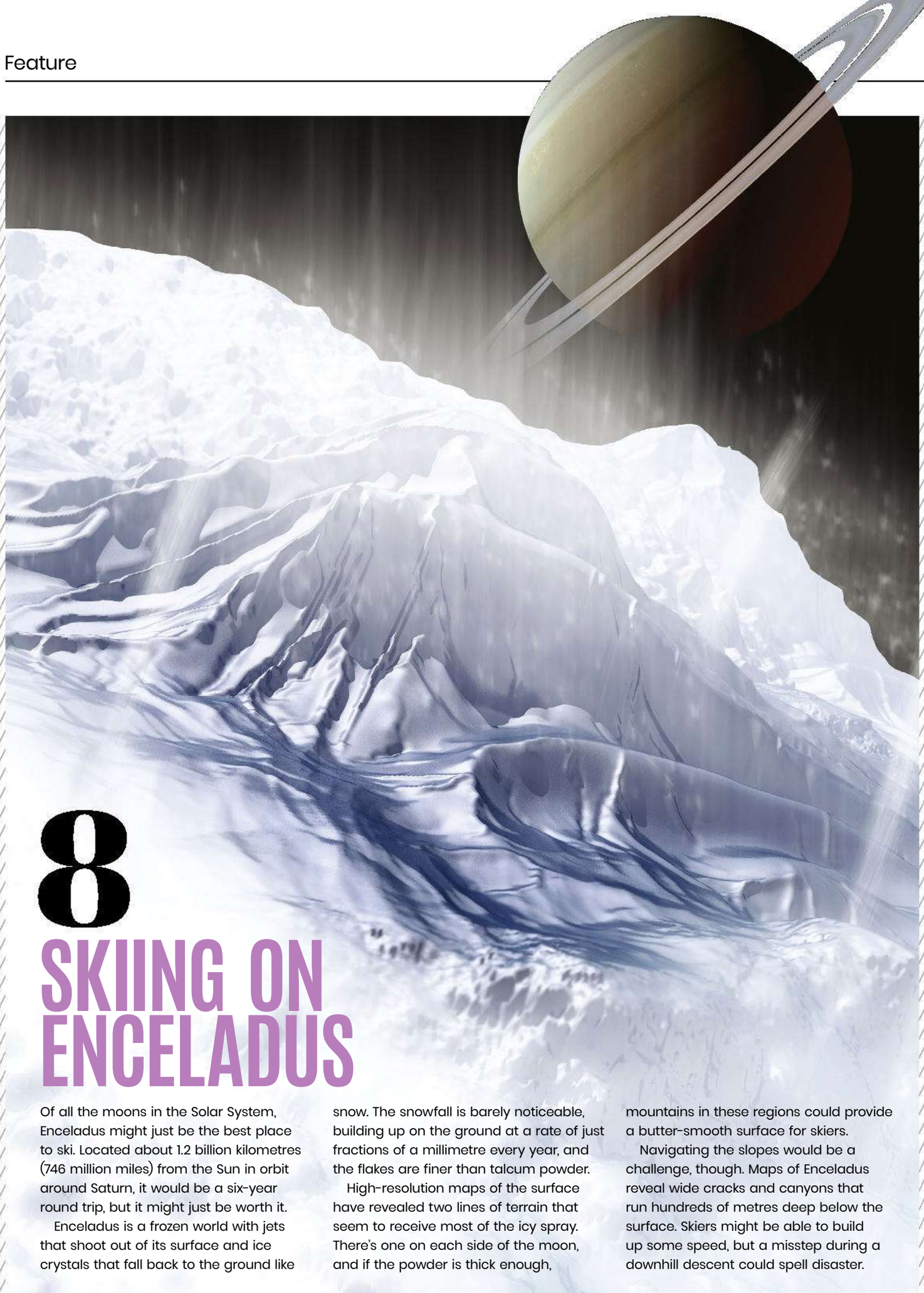
It would be a slow start, but after three years of solar-windsurfing you could be travelling at speeds of up to 240,000 kilometres (149,129 miles) per hour, blowing Earth's best windsurfers completely out of the water.

7 NAVIGATING AN ASTEROID BELT

In science fiction, asteroid belts are dangerous places, littered with chunks of rock spinning wildly in all directions. The asteroid belt between Mars and Jupiter contains an estimated 1.2 million chunks of rock more than a kilometre (0.62 miles) wide – bigger than the tallest skyscrapers. The smaller chunks are uncountable. Each has the potential to be a deadly hazard to spacecraft. When faced with a similar field of rocks, *Star Wars*' C3P0 predicted the chance of a successful trip through was just 1 in 3,720. He was wrong.

A dozen spacecraft have made it through our asteroid belt unharmed – a 100 per cent success rate – and there was no impressive flying involved. In fact, when Cassini travelled through in 2000, no adjustments were made to the flight path at all. Planetary scientists suggest that a similar trip through our asteroid belt would be fairly easy. The asteroids are so far apart that the chances of a craft colliding with one of these lumps of space rock are less than one in a billion. You could probably do it with your eyes closed.





8 SKIING ON ENCELADUS

Of all the moons in the Solar System, Enceladus might just be the best place to ski. Located about 1.2 billion kilometres (746 million miles) from the Sun in orbit around Saturn, it would be a six-year round trip, but it might just be worth it.

Enceladus is a frozen world with jets that shoot out of its surface and ice crystals that fall back to the ground like snow. The snowfall is barely noticeable, building up on the ground at a rate of just fractions of a millimetre every year, and the flakes are finer than talcum powder.

High-resolution maps of the surface have revealed two lines of terrain that seem to receive most of the icy spray. There's one on each side of the moon, and if the powder is thick enough, mountains in these regions could provide a butter-smooth surface for skiers.

Navigating the slopes would be a challenge, though. Maps of Enceladus reveal wide cracks and canyons that run hundreds of metres deep below the surface. Skiers might be able to build up some speed, but a misstep during a downhill descent could spell disaster.

9 WALKING ON A NEUTRON STAR

Neutron stars are some of the densest objects found in the universe. They are more massive than the Sun but are barely more than 25 kilometres (15.5 miles) across. These strange objects are formed when massive stars die; as they run out of fuel, there's nothing to oppose the force of gravity and the layers of dust and gas come crashing in. They pack tighter and tighter together until electrons and protons start to fuse. This produces neutrons, hence the name 'neutron star'.

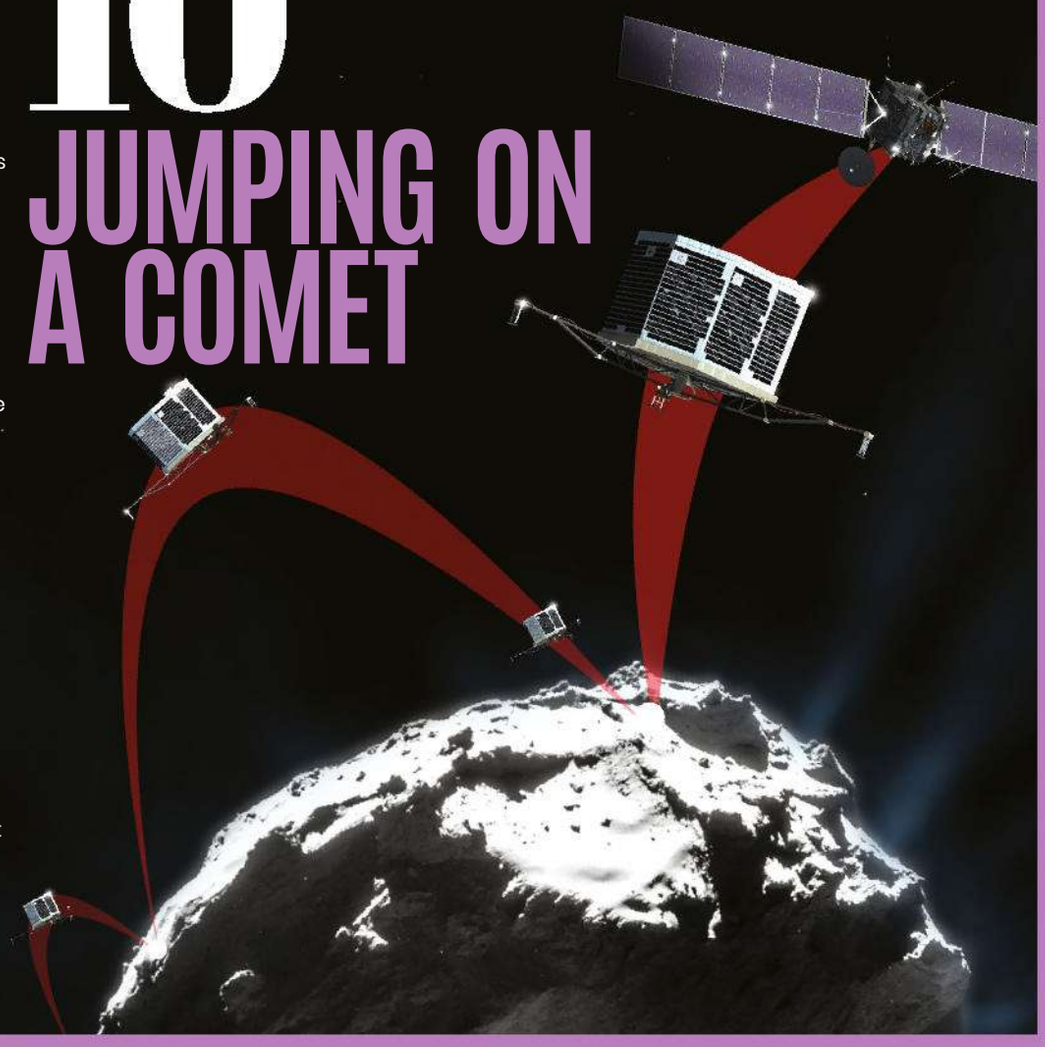
If you could step onto a neutron star, the gravity would be so intense that you would be flattened under the weight of your own body. But if you could survive, what would it be like on the surface?

A star spins faster when its mass crunches inwards, just as a ballet dancer brings their arms in to rotate faster, and neutron stars really do spin quickly. They rotate thousands of times every second. If you could stand on the surface, days would blur into nights in less than the blink of an eye, and holidays would be over before they had even begun. Gravity is so strong that light would be visibly bent, and the magnetic field is so strong that there would be electric currents on the surface.

10 JUMPING ON A COMET

The historic landing of the Philae probe in 2014 is a demonstration of how easy it would be to misjudge a jump on the surface of a comet. At just 4.5 kilometres (2.8 miles) across, 67P/Churyumov-Gerasimenko isn't much larger than a town, and as a result its gravitational pull is hundreds of thousands of times weaker than the one we are used to. Even on the moon, astronauts struggled to keep both feet on the ground, bouncing from place to place rather than walking, but on a comet the effects would be even more dramatic.

In 2014, when the fridge-sized Philae lander approached the surface of 67P/Churyumov-Gerasimenko, it was travelling at less than walking speed and yet it still managed to bounce one kilometre (0.62 miles) up into the sky. But jumping on the comet could end in disaster. According to Rhett Allain, associate professor of physics at Southeastern Louisiana University, an average human in a spacesuit could easily jump 90 kilometres (56 miles) away from the surface of a 67P-sized comet in one bound, leaping clean off the surface and out into space. If you wanted to stay on board long enough to explore, you may have to shuffle.



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FOCUS ON

PUFFY HELIUM PLANETS COULD EXPLAIN AN EXOPLANET SIZE MYSTERY

The fate of Neptune-like worlds that migrate close to their stars is to be whittled away by stellar radiation

Reported by Tariq Malik

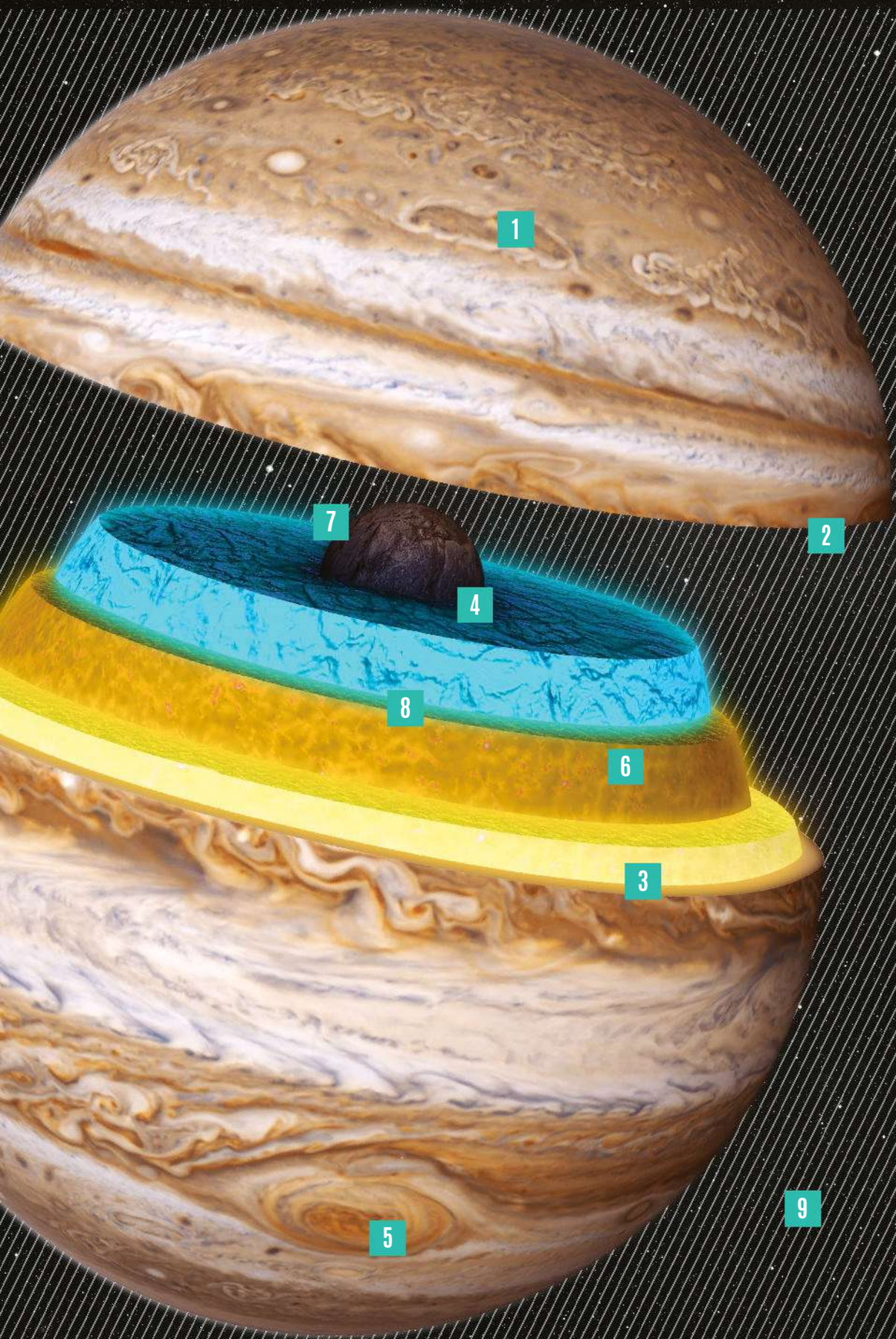
Helium could make up almost half the mass of the atmospheres of giant exoplanets that have migrated close to their stars, explaining why there's a mysterious size gap among these worlds. Over 5,200 exoplanets have been confirmed, and many are larger worlds that orbit close to their stars, in some cases with orbital periods lasting just a few days. However, transit observations by NASA's Kepler Space Telescope and now TESS, the Transiting Exoplanet Survey Satellite, have found a puzzling dearth of planets with radii between 1.4 and 2.4 times that of Earth. Astronomers call this the 'radius valley'. Though it seems to be telling us something fundamental about the nature, formation and evolution of planets, scientists have yet to ascertain what that something is.

A new take on the radius valley from a team led by PhD student Isaac Malsky of the University of Michigan and Leslie Rogers of the University of Chicago suggests it could signal an increasing abundance of helium gas in the atmosphere of worlds 2.4 times larger than Earth. Worlds of this scale are often described as mini-Neptunes – if they have a rocky core, it's deep beneath a thick swathe of atmosphere. Early in their lives, while still forming, planets that formed farther out from their star can migrate inwards. The closer they move to their star, the more they are impacted by the star's heat and radiation, a mix of stellar wind and flares that can gradually remove an atmosphere from a planet. As this happens, a planet can grow a comet-like tail as gas is stripped away. The atmospheres of such worlds are made largely from hydrogen and helium. Jupiter is a good example of this atmospheric make-up, being 90 per cent hydrogen and 10 per cent helium. However, hydrogen is lighter and can escape into space easily.

Designing a computer model, Malsky and Rogers' team found that hydrogen was removed quicker than helium, resulting in the abundance of hydrogen decreasing relative to the amount of helium present. In the most extreme circumstances, some of the planets that they simulated had atmospheres that were over 40 per cent helium by mass. These helium worlds would occupy the bottom end of the higher size range – around 2.4 times larger than Earth by radius. Whether they have an atmosphere rich in hydrogen or helium, the heat from their nearby star would still cause the atmosphere to become bloated and expand, increasing the radius of the planet.

Smaller worlds on the other side of the radius valley, with radii of 1.4 times that of Earth or less, would have lost all their hydrogen and helium and would have no significant atmosphere, limiting their radius to just that of their rocky core. It's possible having lost their primordial atmosphere, these planets could then outgas a new, thinner atmosphere similar to Earth's. But if they are much closer to their star than Earth is to the Sun, they would face a battle to hold onto this new atmosphere too.

An illustration of a star slowly evaporating an orbiting planet's atmosphere



INSIDE A GAS GIANT

1 Surface
The surface of Jupiter is mostly ammonia crystals and sulphur, which form swirling clouds and storms.

2 Orbit
Jupiter orbits the Sun at 780 million kilometres (485 million miles). In other star systems, gas giants can orbit even closer to their stars than Mercury does.

3 Body
Jupiter is built up of layers. The closer to the core it gets, the denser the layers are.

4 Core
Jupiter's core is composed of rock surrounded by a layer of metallic hydrogen.

5 Great Red Spot
This storm on Jupiter's surface has been raging for at least 350 years and is three times larger than Earth.

6 Gravity
The mass of Jupiter's core means the gravity on the planet is 2.4 times that of Earth.

7 Temperature
Jupiter's core is an incredibly hot 35,000 degrees Celsius (63,000 degrees Fahrenheit).

8 Composition
90 per cent of Jupiter is hydrogen, 10 per cent is helium and there's a tiny smattering of other gases.

9 Ring
It was discovered in 1979 that Jupiter has a ring around it like Saturn, however Jupiter's is much fainter.

© Getty

MYSTERIES OF THE UNIVERSE

WHY IS MARS STILL VERY MUCH ALIVE?

A mantle plume may be causing volcanic and seismic activity on the Red Planet

Reported by David Crookes

For a long time, scientists believed that Mars was not only red, but dead. This didn't make the planet any less interesting, since there's evidence of rivers flowing into lakes and the potential that Mars may have once harboured life. But just one look at this small, ghostly world appears to suggest that it's a largely dry and dusty husk. Not much, it has been assumed, has happened on Earth's neighbour for the past 3 billion years. Or so it was thought. "The geological history of Mars was understood to be very simple," says Adrien Broquet, a postdoctoral research associate at the University of Arizona's Lunar and Planetary Laboratory. "The planet formed at the same time as Earth some 4.5 billion years ago, and there was a tremendous amount of volcanism about 3 to 4 billion years ago. Enormous volcanic activity formed the largest volcanoes in the Solar System, for example Olympus Mons. Since then, Mars was understood to have slowly cooled down, with less and less volcanic activity."

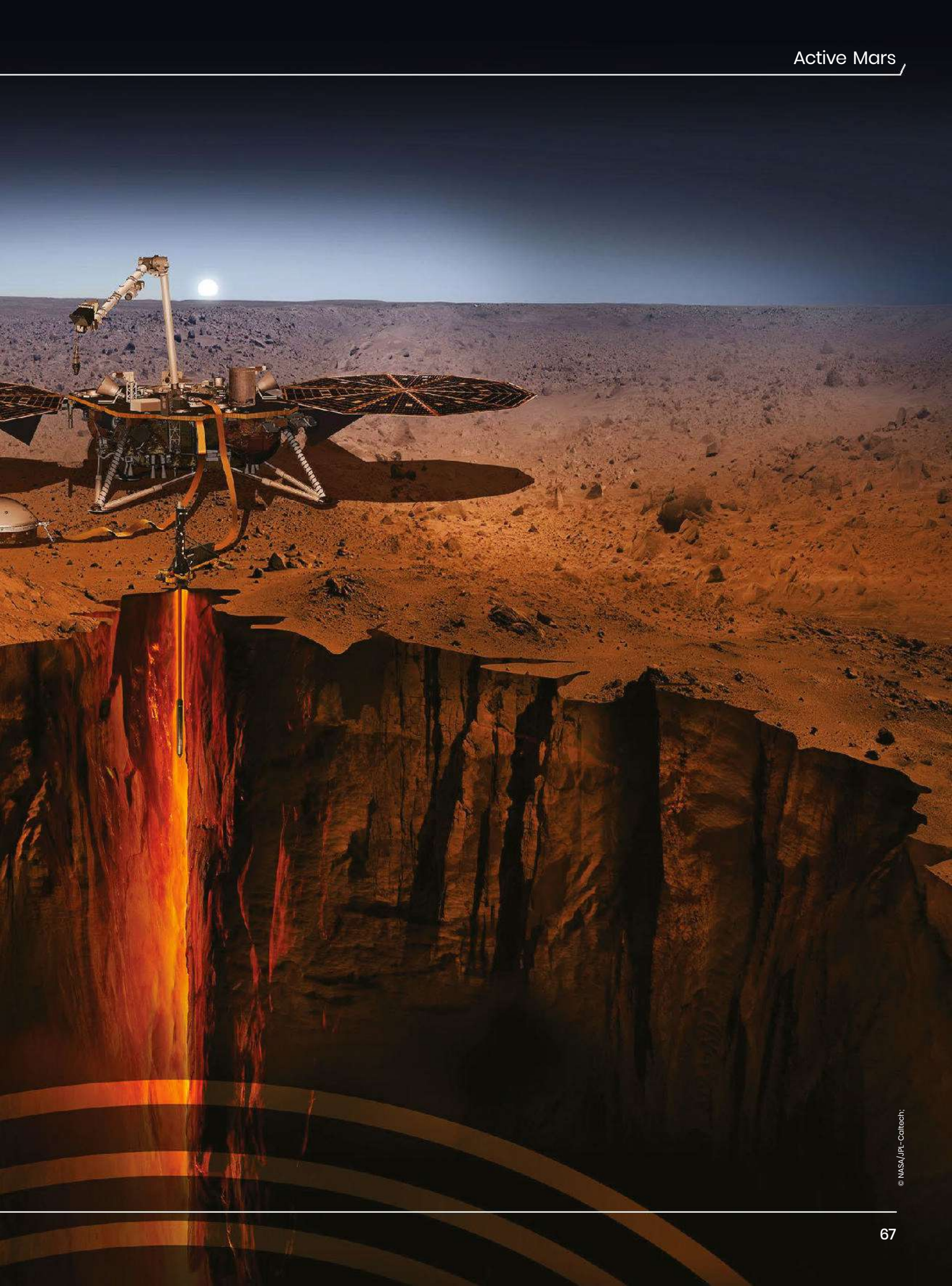
After 2018, the scientific perception of Mars began to change. That year, NASA launched the InSight mission, which sent a lander to the Red Planet to investigate its interior structure and composition. By studying Mars' crust, mantle and core, the mission sought to get to the bottom of how rocky planets formed in our inner Solar System while also determining the level of tectonic activity on Mars. "Before the mission, we kind of expected marsquakes – quakes on Mars – to come from everywhere on the planet, being due to the planet slowly cooling and contracting," Broquet explains. "What we found instead was one particularly active region where maybe 90 per cent of the marsquakes were recorded – some 1,300 in the four years of the mission. This region is called Elysium Planitia, and we didn't know why marsquakes would come from this area specifically. I was doing my PhD in the south of France when we slowly began to understand that this region was seismically active."

Hints of geological activity surprised scientists, but more revelations were to follow. As more attention was paid to Elysium Planitia, which is a plain within Mars' northern lowlands, close to the planet's equator, teams found evidence of young lava flows, and yet that's still only half the story. "It was extremely young lava," Broquet says. "It was less than 100 million years old, which geologically speaking is very young. We were saying the region was seismically active and also volcanically active in the very recent past."

Attempts were made to pinpoint when the last explosion of volcanic ash may have taken place. A team at the University of Arizona found tiny ash deposits, somewhere around 30-kilometres (37-miles) wide, and tried to date them. "Usually, in planetary science, when you try to date something, you count the number of craters at the surface. The more you find, the older the feature will be," Broquet explains. "They found almost no craters, so they could only say this region was younger than 200,000 years old." There are also signs of an eruption within the past 53,000 years.

NASA's Insight probe was thought to have landed in a geographically boring region of Mars. Instead it appears to have landed on an active plume head

A 53,000-year-old ash deposit from one of the fissures of the Cerberus Fossae system



© NASA/JPL-Caltech;

MARS ACTIVITY BY NUMBERS

3 TO 4 BILLION
Years since Mars was most active

200 MILLION
Years over which there have been large eruptions at Elysium Planitia

90%
of recorded marsquakes come from this region

1.6 KILOMETRES
Distance that Mars' crust has been locally pushed up

53,000
Years since the youngest known Martian volcanic eruption happened

4,000
Width of the mantle plume at Elysium Planitia in kilometres

144 MILLION SQUARE KILOMETRES
Surface area of Mars – about the same as the surface of the continents on Earth

It was a startling find. Mars, it could be surmised, was very much alive. As Broquet's study co-author Jeffrey Andrews-Hanna, an associate professor of planetary science at the Lunar and Planetary Laboratory, says, such a timescale is "essentially yesterday" in geologic time. "It means the region is volcanically active today, and because we've recorded marsquakes coming from there, it's seismically active today too," Broquet adds, explaining that most of the quakes are coming from a 1,300-kilometre (800-mile) wide system of young fissures known as Cerberus Fossae, located at the centre of Elysium Planitia. But what's causing this activity? That, it would appear, has been something of a mystery.

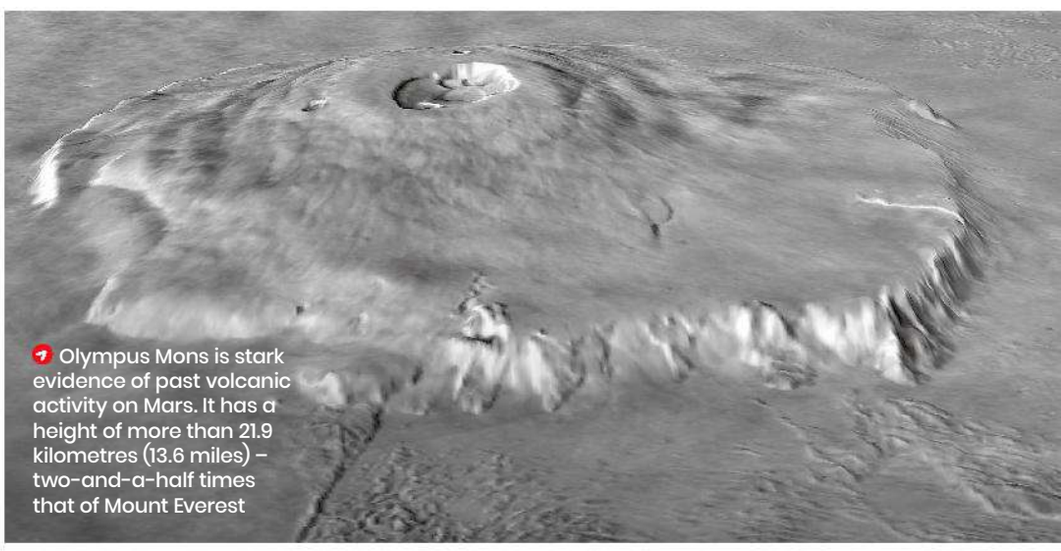
Marsquakes are formed in a similar way to the quakes on our planet, but the cause is different. Earthquakes form when there are sudden movements along faults within Earth's crust. "The surface is fragmented into different plates, and large-scale movement in Earth's mantle causes them to move," Broquet says. Indeed, on Earth, both volcanic and seismic activity are usually associated with plate tectonics. "But there are no plate tectonics on Mars. We know this for sure. There was maybe a stage of plate tectonics shortly after the planet formed, but definitely not today."

Since this rules out one explanation for Mars' volcanic and seismic activity, scientists have looked for other potential causes. In their study, published in *Nature Astronomy*, Broquet and Andrews-Hanna propose the presence of a giant active mantle plume on Mars. It's a controversial hypothesis to some extent. "Most scientists like the idea of mantle plumes, but there are some who do not," Broquet says, but there's nevertheless a stack of evidence pointing to their existence.

Mantle plumes are an upwelling of hot, rocky material from a planet's deep mantle. The mantle is solid rather than a liquid, but it can flow, gradually, over geological time scales and bubble to the surface, reaching the base of a planet's crust to cause volcanic eruptions, faulting and quakes. On Earth they're said to be the cause of volcanic hotspots such as Iceland and Hawaii. "If you analyse the composition of the lava in Hawaii, it's peculiar" says Broquet. "Geologists tell us the only way to make these peculiar rocks is to have them coming from the deep mantle." There is also evidence of mantle plumes on Venus. "We have evidence of very recent volcanism on Venus, and features called coronae, which are large depressions," he says. "A lot of scientists think these are formed by mantle plumes because they have characteristics that we can link to them."

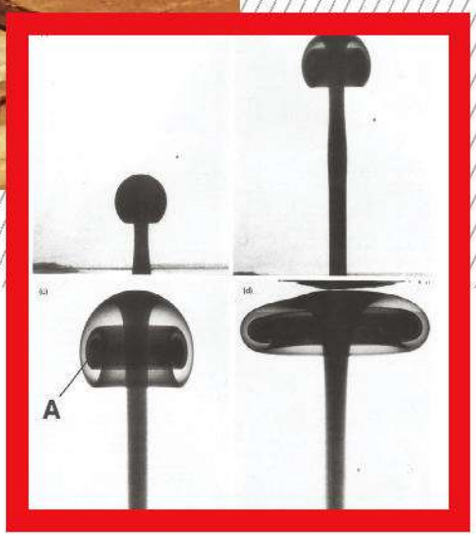
So what exactly appears to be happening on Mars? "We think that mantle plumes form very deep within a planet's mantle – at the base of the mantle, just on top of the core," Broquet says. "For Mars that would be 1,550 kilometres (960 miles) below the surface, so very, very deep. You have to think of it like a lava lamp. The mantle material is warmed locally, causing it to become buoyant. It then floats and goes upwards very slowly – about

"This region is called Elysium Planitia, and we didn't know why marsquakes would come from this area specifically" Adrien Broquet



Olympus Mons is stark evidence of past volcanic activity on Mars. It has a height of more than 21.9 kilometres (13.6 miles) – two-and-a-half times that of Mount Everest

The European Space Agency's Mars Express orbiter has taken an image showing one of the fractures that make up Cerberus Fossae



This is what scientists think a mantle plume looks like, based on a laboratory experiment

the speed your fingernails grow – rising through the mantle.

"When it reaches the base of the crust, the very thin and rigid layer on top of the planet, it cannot penetrate because the crust is viscous. Instead the plume material flattens at the base of the crust, adds heat to the crust and causes the crust to be uplifted with respect to the surroundings because you have this plume material pushing below the surface. It's this uplift that likely fractured the crust, forming the Cerberus Fossae fissures in the recent past, and that is currently causing the observed seismic activity. This was the first evidence that we tried to look for, and this is exactly what we found, starting this whole project. We found that the surface within this region is elevated by about one to two kilometres (0.6 to 1.2 miles) with respect to the surroundings. The diameter of this elevated region is about 4,000 kilometres (2,400 miles), which is the size of the continental US."

The centre of the mantle plume is found to be exactly underneath Cerberus Fossae, and the plume is estimated to be anywhere between 95 and 285 degrees Celsius (170 and 520 degrees Fahrenheit) hotter than its surroundings. But while scientists appear to have an explanation for recent volcanic and seismic activity, one big question remains... why now?

"It's something that puzzles me, and I cannot explain it," Broquet says with a shrug. "Why did Mars likely have lots of plumes in the past, lots of activity, nothing for 3 billion years and then, suddenly, something again? I've talked with colleagues who try to monitor how much heat is being produced

THREE POTENTIAL EXPLANATIONS

Scientists are trying to work out why Mars became active again

Tectonic plates

NASA's Insight lander found an active fault zone in the Cerberus Fossae area of Mars in 2019, and marsquakes of magnitude 3.0 and 4.0 were detected. But Mars is made up of a static crust around a rocky mantle. It doesn't have plate tectonics – the movement of which causes quakes on Earth, so this theory can be ruled out.

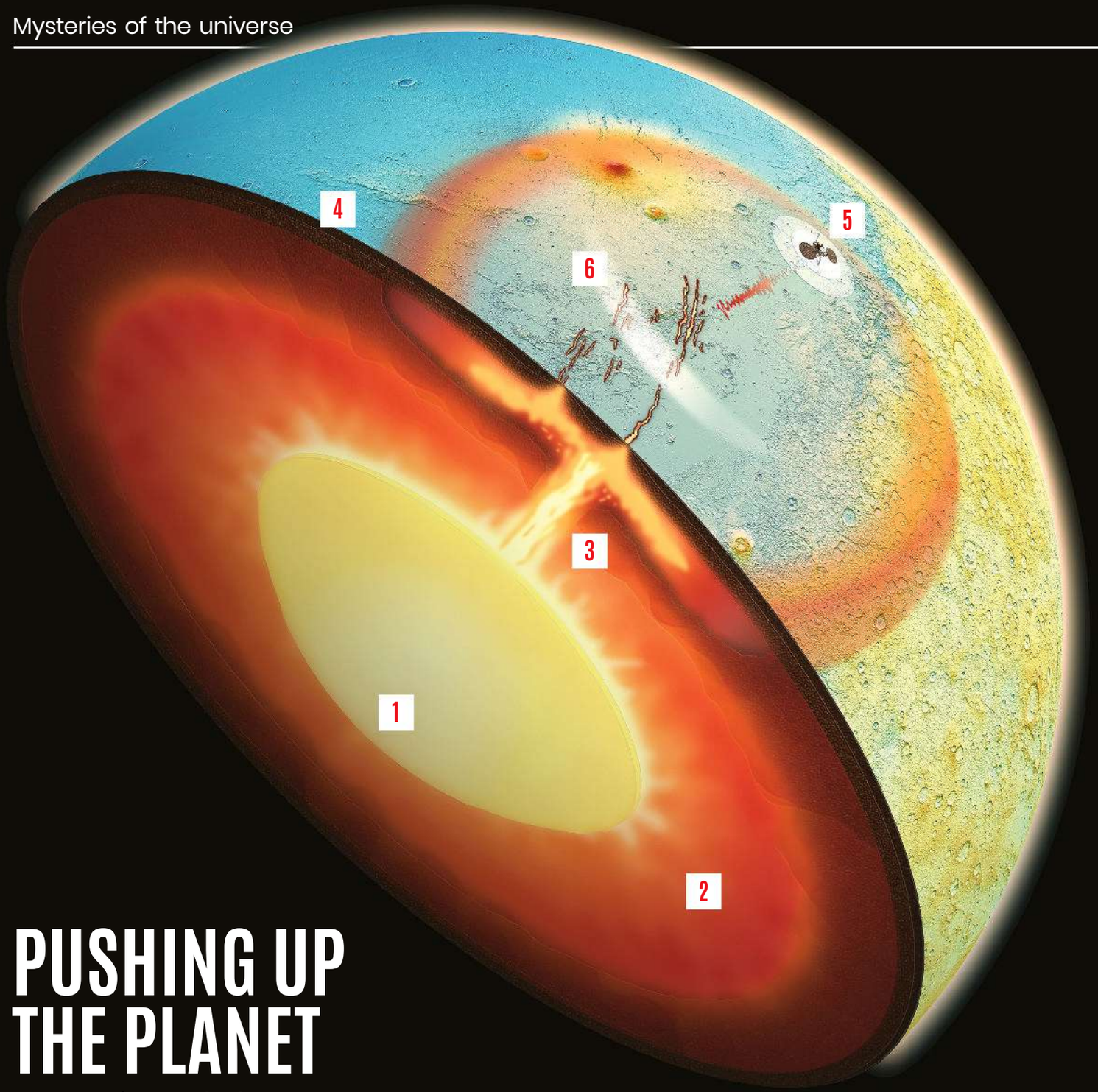
Meteoroid impacts

A massive meteorite impact could cause quakes or puncture a planet's crust to trigger a volcanic eruption. Some marsquakes were attributed to impacts, but those from Elysium Planitia originate from deep underground. An impact could trigger an eruption, but you'd still need some magmatic activity underground.

Mantle plumes

The latest study suggests that a plume has been bubbling up in the Elysium Planitia region of Mars and that it's causing seismic and volcanic activity. If this is the case, it means there's still a small yet significant amount of energy within the planet. For this to happen, Mars cannot have cooled as quickly as scientists thought.

© ESA/DLR/FU Berlin; Griffiths & Campbell 1990



PUSHING UP THE PLANET

How an active mantle plume can push the surface of Mars

1 Mars' core
Just like Earth and Venus, Mars has a core made of iron, nickel and sulphur. The latest results from InSight found it to be 1,830 kilometres (1,137 miles) thick and less dense than previously thought.

2 A rocky mantle
Above the core is a rocky mantle – a layer of molten rock which extends 1,560 kilometres (969 miles) below the surface. It's made of silicon, oxygen, iron and magnesium.

3 Mantle plume
An enormous blob of warm solid mantle material is said to form and rise over an extremely long timescale. It pushes through the mantle, continuing upwards. Visually, it could look like the blobs you see rising in a lava lamp.

4 Crust collision
The plume eventually reaches Mars' crust, made of iron, magnesium, aluminium, calcium and potassium. It pushes the crust upwards, and this brings hot magma to Mars' surface while also causing marsquakes.

5 InSight lander
This is the location of the now-retired InSight lander. You can also see the extent of the plume in red.

6 Marsquake position
The white shading points to the estimated position of most marsquakes that have been recorded. You can see the Cerberus Fossae series of fissures too.

© Adrien Broquet and Audrey Lasbordes

within the planet and being lost due to volcanism, and none of our models predict mantle plumes forming today. But what I know is that these models, although having a lot of complexity, also make some fairly simple assumptions, and my guess is that there is something important that we do not yet understand. Maybe there are some very-long-timescale processes in the core of Mars, and when all of these different processes, some of which may be small, build up to make a big, terrible anomaly somewhere, it could give rise to a plume."

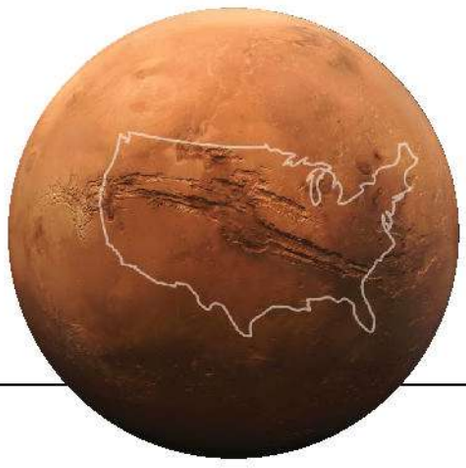
The study flies in the face of previous expectations – those of Mars being very active in the past, slowly cooling down and having less and less volcanic activity. A recent or ongoing resurgence in the volcanism of Mars had never been predicted. "The models that we currently have just don't explain it," Broquet affirms. "But now that the study is out, scientists can start to think differently. It's a paradigm shift." He draws parallels with past findings about the Moon. "When we went to the Moon with the Apollo program, the scientific view was that it was a solid, dead rock because it was smaller than Earth and didn't have plate tectonics, meaning it should cool fairly quickly," Broquet says. "But when we sent seismometers to the Moon, we found the core was molten. It was a big surprise because no one was expecting that. We understood that worlds with no plate tectonics – even though they're smaller than Earth – may not cool as fast as we thought. It's probably something similar to Mars."

One consequence of the study is the renewed expectation that life could be found on the Red Planet. Elysium Planitia is thought to have hosted vast volumes of water ice in its crust. Whenever an eruption took place, ice melted, interacted with lava and flooded from the Cerberus Fossae fissures up to 10 million years ago. But Broquet attempts to play down such talk: "It's very important, and I know the press likes to latch on to talk of life, but there are a lot of ifs," he says. However, he doesn't rule it out. "In this region there's a smaller area called the Athabasca Valles, and its surface is extremely chaotic," Broquet says. "You can see very long turbulent lava flows – by which I mean they go in all places, are mixed and carved into the surface – and the only way to make these turbulent flows is to have interaction between lava and water.

"This is something that is fairly well understood on Earth. When you have water in the crust and lava that goes through this water pocket, you can have some very explosive activity. The interaction between lava and water in the Athabasca Valles happened fairly recently, about 100 million years ago, so it's very likely there is water ice on the ground on Mars today. "The Phoenix lander highlighted this when it landed close to the poles, scratched the surface with a little shovel and uncovered white and bright deposits underneath the dust. Some people thought it was salt or some minerals, but the material disappeared within a few days. You don't have lots of wind on Mars, and it was a bit deeper than the surface, leaving water ice exposed to the surface temperature as the answer.

"If you have a mantle plume in Elysium Planitia, this will warm the crust locally and could melt water ice. You could expect some pockets of liquid water, and we know that whenever you have liquid water and a source of heat on Earth, you have microbes that flourish. So yes, our study has implications for the biological potential of the region." For now, however, Broquet is concentrating on why and how a plume could have recently formed. "What would be best is to send another mission to Elysium Planitia," he says. "But in the meantime, we will try to work with people building thermal evolution models of Mars and convince them that an active giant mantle plume is the only explanation for everything we have seen in the region. My goal is to make sure I haven't missed anything. One of the most exciting things is seeing how people will seek to explain just what is going on."

Hawaii is said to have formed when the Pacific plate on Earth drifted over a mantle plume



The giant plume is about the size of the continental US. This graphic gives an indication of its scale

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

© NASA/JPL-Caltech; Warren Ishii/Getty

FOCUS ON

‘PNEUMOPLANET’ INFLATABLE MOON HABITAT COULD HOUSE 32 ASTRONAUTS

Humanity is going back to the Moon to stay, and we might have a way to live there long term

Reported by Laurence Tognetti

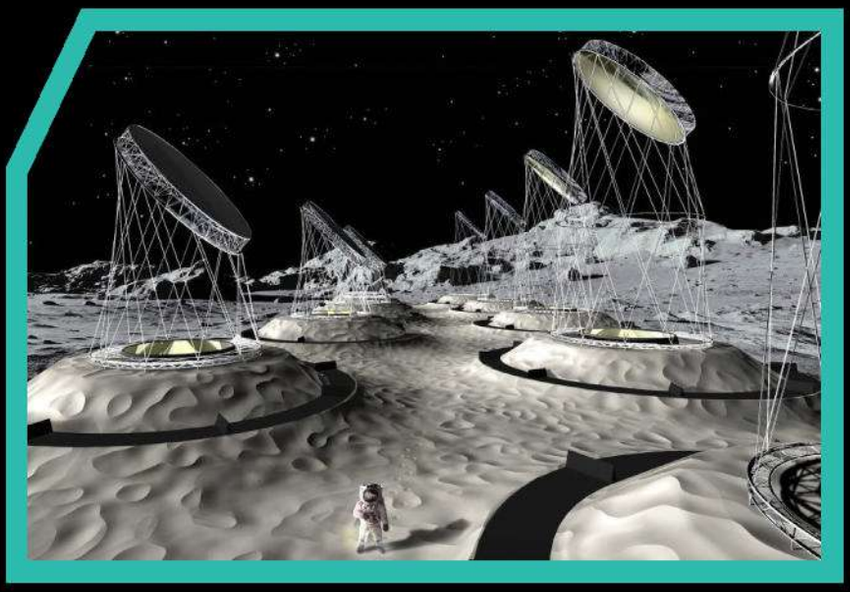
Recently, NASA established potential landing sites near the south pole of the Moon for upcoming crewed missions of its Artemis program. But how will astronauts survive and thrive in the harsh lunar environment? One new proposal could help. Austrian company Pneumocell has developed the PneumoPlanet inflatable habitat concept for the Moon, which could contain up to 16 greenhouses and house up to 32 astronauts. “PneumoPlanet is an ultra-light inflatable structure covered by regolith that will operate self-sufficiently by producing and recycling its own oxygen and food using solar power,” said Philipp Gläser, a postdoctoral researcher at Berlin Technical University and a co-researcher on a study outlining the PneumoPlanet concept. “It can therefore serve as a permanent lunar outpost, enabling various future missions to use it as a base. The habitat protects against cosmic radiation and micrometeorites, keeping the crew safe and allowing for longer mission durations.”

PneumoPlanet has received funding from the European Space Agency. New research suggests the habitat be located near one of the lunar poles, where sunlight is more plentiful, given the Moon’s extremely slight

axial tilt. Ideally, PneumoPlanet would be set up close to a permanently shadowed region (PSR), a polar crater floor that has been in darkness for aeons and therefore might harbour large amounts of water ice. The architect and lead designer of PneumoPlanet is Thomas Herzig, who is also the founder and CEO of Pneumocell. Herzig said he's passionate about PneumoPlanet and its potential for assisting future astronauts, stressing that no other habitat concept offers what PneumoPlanet can in terms of the overall design, specifically pertaining to the greenhouse. "All the effort and energy for 3D printing of massive walls and ceilings isn't necessary," Herzig said. "The most important innovation lies in the mirrors that reflect the visible sunlight in an optimal wavelength range into a greenhouse, while all the harmful particle radiation is kept out. Inside that greenhouse, we can self-sufficiently produce oxygen and food in a natural way from natural sunlight only, and the greenhouse also is a natural living space for the crew."

PneumoPlanet's mirrors will be hoisted with carbon-fibre tubes on a rotating magnetic ring that will track the direction of sunlight. This will allow natural sunlight to pass through a transparent foil and enter the greenhouses with 65 kilowatts of energy, which is equivalent to 265 watts per square metre – ideal for photosynthesis to take place. With humans scheduled to return to the lunar surface in the next few years with the Artemis missions, could PneumoPlanet be a viable tool for their habitat? "While several nice renderings of Moon habitats have been released to attract the attention of the public, until now, no permanent and sustainable Moon base is part of the planned Artemis missions," Herzig said.

He described the current big-picture plan for Artemis, which involves building a small Moon-orbiting space station called Lunar Gateway to send astronauts to the surface and having them sleep in a rover there for a few days. However, NASA has outlined plans to establish some infrastructure, potentially near PSRs on the lunar surface and including a four-person habitat, as part of its Artemis Base Camp outpost. Herzig also noted that the Gateway will not have the same benefits of protection from cosmic radiation as the International Space Station, since the latter orbits within Earth's magnetic field. "I think it's a pity to put all that effort into a lunar space station instead of building something on the Moon, where you can use the resources of the Moon, provide better safety and comfort for the crew and conduct experiments and industrial processes on the Moon," Herzig said. "But since the Artemis mission has been delayed so many times, maybe NASA will change its mind about Lunar Gateway and a permanent Moon base in future."



Artist's illustration of Pneumocell's proposed PneumoPlanet habitats on the surface of the Moon

© Alamy

SPACE EXPLORATION

How did we find an ocean on Enceladus?

The first confirmation that there was a liquid layer about 35 kilometres (21.75 miles) below the south-polar terrain came from the gravity signature. The distribution of mass under the south-polar terrain was detectable by carefully tracking the motion of the Cassini spacecraft as it flew closely over Enceladus' south pole. Doing three such flybys allowed the gravity team to figure out that the water layer had to be about 35 kilometres (21.75 miles) beneath the surface and about ten kilometres (6.21 miles) thick.

The confirmation that the ocean is global came from noticing how the rotation of Enceladus wasn't uniform, but sometimes slightly faster and sometimes slightly slower. To do this, my team members were using features on the surface as benchmarks – kind of like painting a white stripe on your car tyre – and comparing the positions of the features at various times to see how they compared to where they would have been if there were no wobble. And the magnitude of the wobble indicates something about the interior – in particular whether the ice shell moves independently of the core or is attached to it. In this particular case, they found that the ice shell has to be moving independently, and that can only be the case if it's floating on a liquid layer.

"The first confirmation of a liquid layer came from the gravity signature" **Carolyn Porco**

Carolyn Porco, an American planetary scientist who led the imaging science team on the Cassini mission

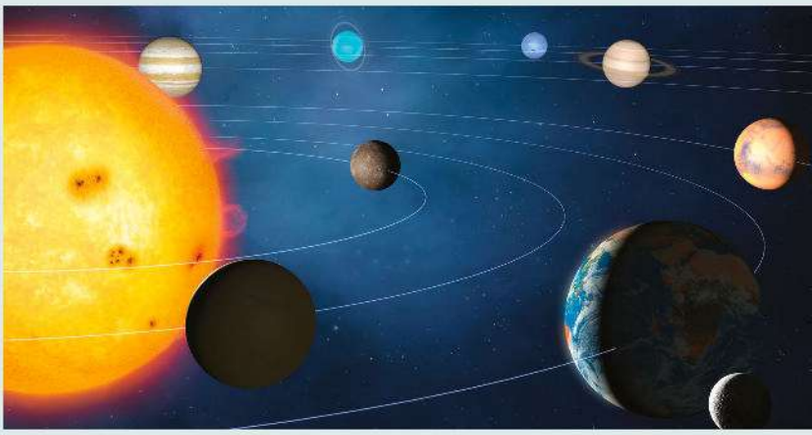
© Getty:

HUNT FOR LIFE

Is there life on other planets in the Solar System?

There could be evidence on other planets in the Solar System – maybe on the satellites around giant planets such as Jupiter or Saturn. There's the possibility of life in the oceans inside these big, big moons, like Europa, because they have liquid water in their interiors. However, these hypotheses are really just speculation because we have no concrete evidence of life in another place in the Solar System, except Earth. And far away? No.

On exoplanets it's even more difficult to detect life. We are too far away, so we have to detect non-direct evidence. We have to detect products of life such as biosignatures – compounds in the atmosphere. This is evidence for the product of exolife. We have to undergo spectroscopic analysis and other non-direct methods to detect life in other planetary systems. In the Solar System, we can send probes to see if there is life. It's difficult, but it's simpler than exploring exoplanets, as they are too far away. We have to wait for biosignature detections around the planets and to detect special compounds, for example carbon compounds, which could be products of other life. It will soon be possible to detect this signature in exoplanet atmospheres with future telescopes. It's the next step for bioastronomy, people working on exoplanets and people looking for life elsewhere.



Probes haven't found any life out there yet

GPS is found on many devices today

Dr Florence Raulin-Cerceaux, associate professor at the National Museum of Natural History in Paris, France, and a member of the board of directors for Messaging Extraterrestrial Intelligence (METI) International

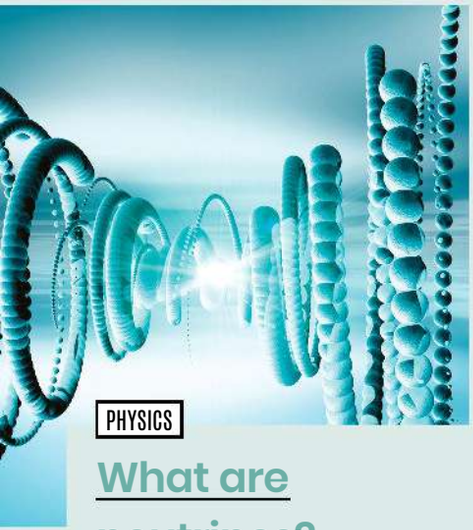
TECHNOLOGY

Whose idea was it to make GPS?

There had been a previous satellite navigation system called Transit. It was, by our standards, quite crude, but it was worldwide. GPS can provide constant coverage to the whole Earth, and Transit couldn't do that. It would give you a relatively crude fix once every two or three hours. It was good enough for some Navy ships, but it wasn't good enough to land aeroplanes. A study was done, and 12 techniques were highlighted as ways to navigate using space satellites. We selected the hardest, which provided four dimensions: latitude, longitude, altitude and very precise time.

Two important breakthroughs had to occur. First, we had to come up with a signal that was very unique. Back then we were experimenting with a new signal that was so quiet that if you looked at the radio spectrum you wouldn't see it at all. Now everyone accepts it as a GPS signal, but there was great scepticism that it could be good enough to navigate. Today we navigate to a millimetre with it. Secondly, we wanted the satellites to go around the Earth, be autonomous and have clocks with stability better than one second in 300,000 years. We were trying to measure time to a fraction of a billionth of a second.

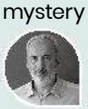
Air Force Colonel Bradford Parkinson, the lead architect for the Global Positioning System (GPS) program



PHYSICS

What are neutrinos?

Neutrinos are one of the most abundant fundamental particles in the universe. They come in three flavours: electron neutrino, muon neutrino and tau neutrino. A neutrino is similar to an electron but has no electrical charge and a tiny mass. Neutrinos aren't part of an atom – in other words, matter, unlike protons, neutrons and electrons. Like other constituents of the Standard Model of particle physics, they're assumed to be point-like objects: they aren't made of any smaller pieces that we know of. According to the Standard Model, there exist 12 fundamental particles, namely three families of leptons – electron, muon and tau and corresponding neutrinos – up and down quarks and their antimatter versions. The most abundant are neutrinos, created in the universe's first second after the Big Bang. Theory predicts that there are 340 Big Bang neutrinos in every cubic centimetre everywhere in the universe. Due to very low energy, they haven't been experimentally confirmed yet. They form a cosmic neutrino background with a very low temperature of about -271 degrees Celsius (-455.8 degrees Fahrenheit). Nowadays, neutrinos remain a mystery for physicists.



Fedor Šimkovic, nuclear physicist at the Department of Nuclear Physics and Biophysics at Comenius University in Bratislava

©: Getty;

PHYSICS

Why is string theory so important?

String theory is elegant because it takes a wealth of phenomena, particle properties and their interactions and it reduces them to one essential idea: the ways that little filaments can vibrate. For example, the string in a cello vibrates in one way and produces one musical note, and it vibrates in a different way and produces a different musical note. In string theory, when these little filaments vibrate in different patterns they produce different particle properties. So the wealth of everything that emerges from the particles comes from the vibration of the strings. Everything is like a cosmic symphony, so it's a very beautiful and elegant idea.

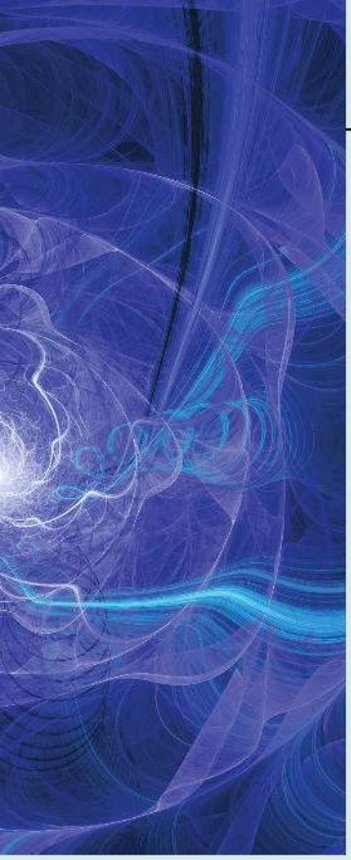
Brian Greene, professor at Columbia University and chairman and co-founder of the World Science Festival

ASTRONOMY

How hard is it to find a comet?

It's very difficult, especially now, because part of what we accomplished with Shoemaker-Levy 9 was to get the world interested in this problem of if there's an asteroid or a comet that could collide with the Earth, and if there is, we'd better find it. Now there's a lot of money being paid into searching the skies for asteroids or comets that could collide with Earth. We have actually found a couple within a few hours of their collisions with us – not a comet, but small asteroids. We missed the one that hit Russia a few years ago. We missed that one because it was very close to the Sun as it was approaching us and we never got to see it, and it collided with us very rapidly. It didn't do any damage, except a lot of broken windows and the scratches that people got. I don't think there were any fatalities and I think everybody was okay, but it did teach us that Earth is a target and we will be hit again. Let's hope we're not hit by any of the big ones.

David Howard Levy, a discoverer of comets and minor planets who co-discovered Comet Shoemaker-Levy 9 in 1993



String theory remains purely hypothetical

Some comets can get close to Earth in their orbits around the Sun

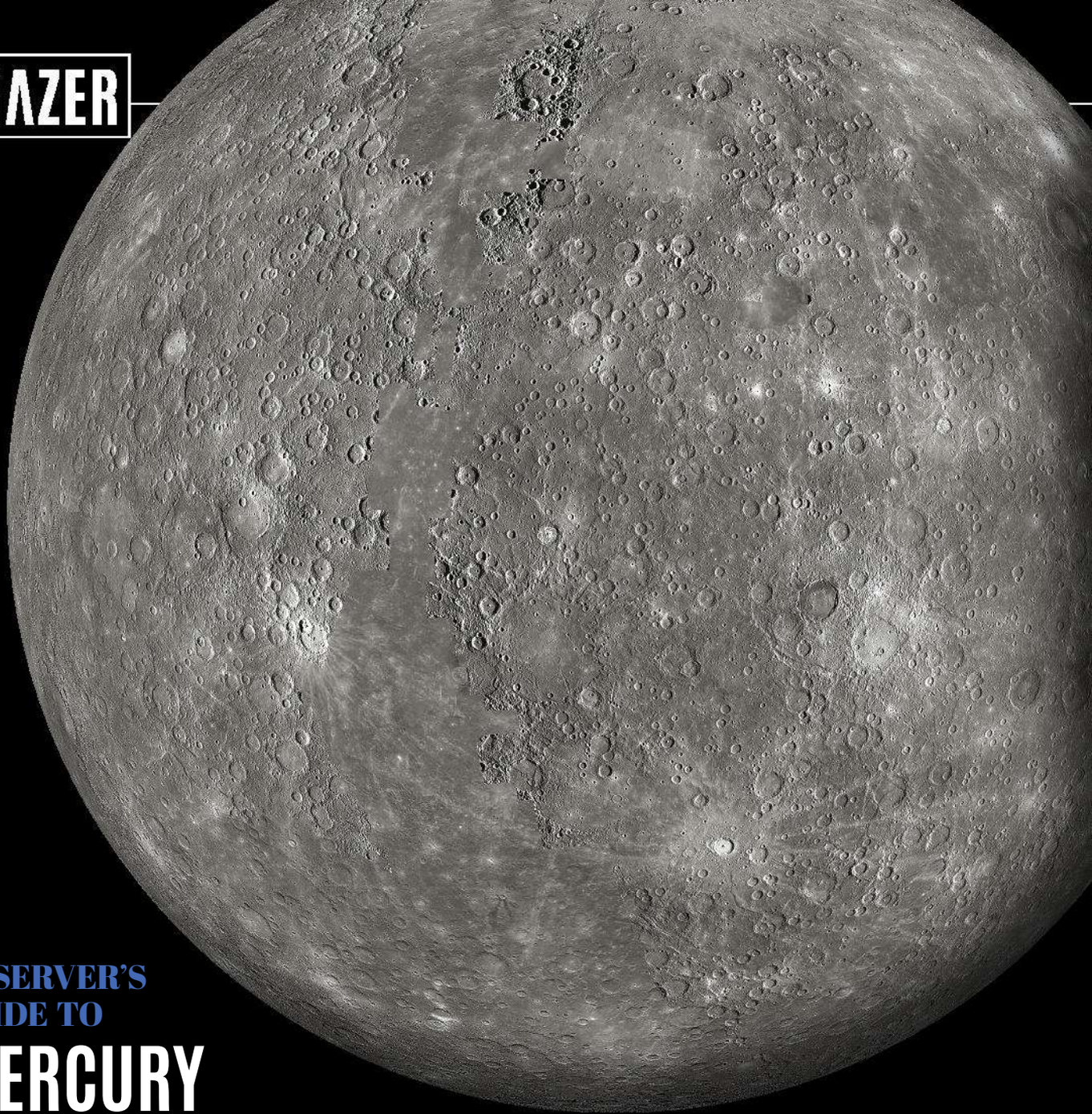
SOLAR SYSTEM

Where on Earth can I go meteorite hunting?

When we were producing the *Meteorite Men* show, Steve [Arnold] and I typically came up with a list of places we'd love to go at the start of each new season and the production team would maybe allow us to do five international episodes and three in the US to fit with the budget. There were places we wanted to go but couldn't because it was too expensive, too dangerous or there were legal reasons such as government restrictions. But Antarctica would be top of the list – thousands of meteorites have been found there. We also know that giant iron meteorites have been found in Cape York, Greenland, and that the Namib Desert in Namibia is a fantastic meteorite site. But there are strict government regulations in West Africa about moving or removing meteorites, and because we always do everything above board, we wouldn't do what some dodgy people do in this business and smuggle them out. That's wrong for numerous reasons: it means cultural property disappears and important meteorites that should have been studied aren't available to academia.

Geoffrey Notkin, a meteorite specialist who has appeared in programmes for some of the world's top broadcasters, including the BBC, National Geographic and PBS. He is best known for co-hosting *Meteorite Men* with Steve Arnold

Small meteorites fall to Earth all the time, though many burn up on entering our atmosphere



OBSERVER'S GUIDE TO

MERCURY

Some seasoned astronomers have never seen this small planet. Here's how you can...

In Greek mythology, Mercury was the messenger of the gods and was quick and elusive. This is probably where the nearest planet to the Sun got its name, orbiting the Sun in just 88 days. Because of this, it's never very far from the Sun in our skies and regularly shifts its location from either the east side or the west side of the Sun. The furthest point east or west, known as an elongation, is therefore the best time to try to see the planet.

To further complicate matters, the altitude above the horizon above which Mercury can be seen can also change, and so not every elongation is favourable for viewing it. This is due to the angle of the ecliptic path – the path that the Sun and planets appear to take across the sky – changing as we orbit the Sun. When the ecliptic path has a steep angle to the horizon, we usually get favourable elongations of Mercury, and therefore stand a much better chance of seeing it.

Because of this, Mercury is only ever visible in twilight skies, either just after sunset or just before dawn depending on whether it's going through an eastern or western elongation. Above all else, if you hope to see this little and elusive planet, you will need to have very clear skies and a clear horizon, with no trees or buildings in the way. Twilight makes it all the harder to spot, but it's not too difficult if you know where you should be looking.

But a warning needs to be issued here. Do not attempt to go looking for Mercury with any optical aid, such as binoculars, a telescope or even a camera, until after the Sun has fully set or a minute or two before dawn, as it would be very easy to accidentally catch the sunlight in your

optics, with all the inherent risks to your eyes that may bring. Desktop planetarium software such as Stellarium will give you a good indication of where you should be able to find the planet on any given date or time, which should help considerably.

"To the naked eye, Mercury will look like a moderately bright star"

To the naked eye, Mercury will look like a moderately bright star, glowing in the twilight with a pinkish hue. Binoculars will show it as something non-stellar, although it will take more magnification than binoculars can usually give to show it as an appreciable disc. Binoculars are very helpful in actually locating the planet. Scanning the area in slow, steady lines, sometimes called 'sweeping', is an effective method of picking up Mercury in the twilight sky. Once it's located, it's much easier to find it again. A small telescope will show its true nature. Mercury will be seen as having distinct phases, like those of the Moon, depending on how far along it is into its orbit around the Sun. This will change over the few days that Mercury will be viewable. At its greatest elongation – the point that it's furthest from the Sun from our point of view – it will show a half phase. In other words, half the disc will be illuminated. It will also be at its brightest.

Larger telescopes with higher magnifications will show a larger disc of the planet, and the phase will be easier to see. But the blurring effects of our atmosphere will make imaging Mercury a challenge through a telescope. Unfortunately, Mercury is just too small and far away to show any features other than its phase in amateur telescopes, but don't let that put you off taking a look. This fascinating world has many secrets yet to be revealed, and surprisingly few amateur astronomers have laid their eyes on it.

WHAT CAN I EXPECT TO SEE?

Naked eye

Not far above the horizon and just after sunset, you should see a moderately bright star.

10x50 binocular

Binoculars will make it easier to spot Mercury, which looks like a tiny version of the Moon.

Small telescope

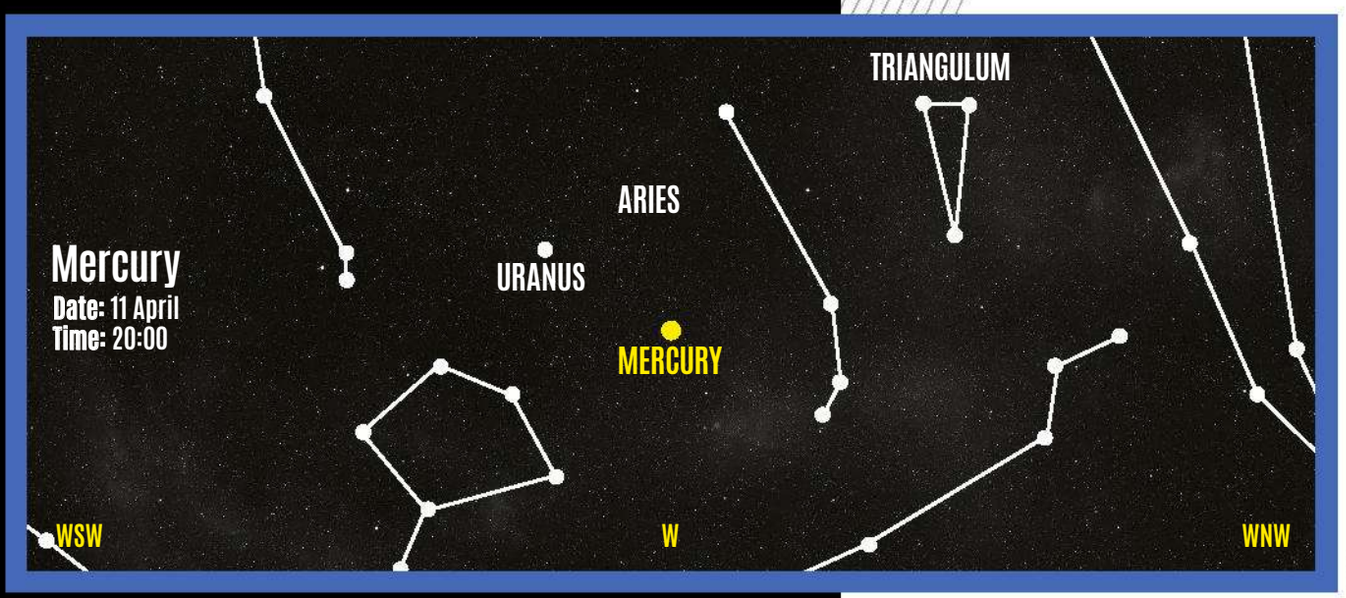
A small telescope will enable you to view the phase of Mercury quite clearly.

Medium telescope

A medium-sized telescope will show the disc of Mercury quite well, as well as its phase.

Large telescope

Mercury appears very bright through a large-aperture telescope, with a distinct phase.



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WHAT'S IN THE SKY?

What to look out for during this observing period

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24 MARCH
The Moon and Venus make a close approach, within 6' of each other in Aries

24 MARCH
Conjunction between the Moon and Venus in Aries

24 MARCH
The Moon passes in front of Venus, visible from Asia and Africa

28 MARCH
Conjunction between the Moon and Mars in Gemini

28 MARCH
The Moon and Mars make a close approach, passing within 2°17' of each other in Gemini

28 MARCH
Comet C/2019 U5 (PANSTARRS) will make its closest approach to the Sun at +11.9 in Virgo

30 MARCH
Dwarf planet Makemake reaches opposition

30 MARCH
Dwarf planet Haumea reaches opposition

3 APRIL
The Sombrero Galaxy (Messier 104) is well placed for observation in Virgo

4 APRIL
Spiral galaxy Messier 94 is well placed for observation in Canes Venatici

9 APRIL
Mercury is at half phase (dichotomy)

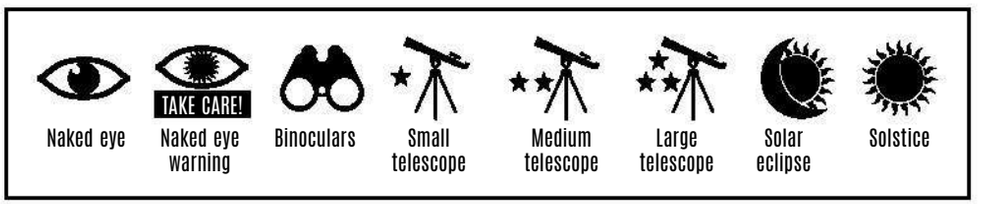
9 APRIL
The Moon will pass in front of Delta Scorpii, creating a lunar occultation

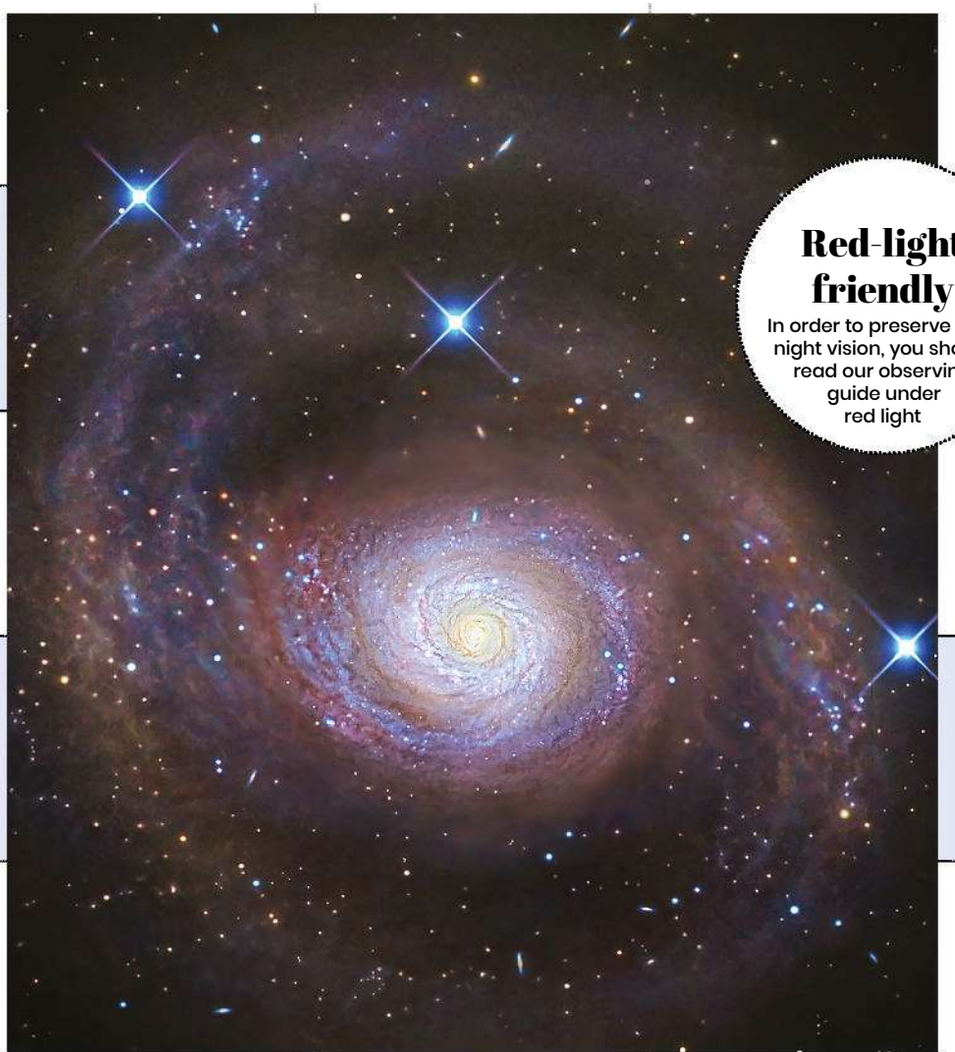
11 APRIL
Mercury is at its highest altitude in the evening sky at magnitude +0.0

11 APRIL
Mercury reaches greatest elongation west in the evening sky at +0.0

15 APRIL
The Whirlpool Galaxy (Messier 51) is well placed for observation in Canes Venatici

20 APRIL
Hybrid solar eclipse visible from western Australia, East Timor and eastern Indonesia





Red-light friendly
In order to preserve your night vision, you should read our observing guide under red light

16 APRIL
The Moon and Saturn make a close approach, passing within 3°11' of each other in Aquarius

16 APRIL
Conjunction between the Moon and Saturn

19 APRIL
Globular cluster Messier 3 is well placed for observation in Canes Venatici

22 APRIL
Conjunction between the Moon and Venus in Pisces

"The Moon passes in front of Venus, visible from Asia and Africa"

Jargon buster

Conjunction
An alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Declination (Dec)
How high an object will rise in the sky. Like Earth's latitude, Dec measures north and south in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and 60 arcminutes in a degree.

Opposition
When a celestial body is in line with Earth and the Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Right Ascension (RA)
RA is to the sky what longitude is to Earth, corresponding to east and west. It's measured in hours, minutes and seconds, as since Earth rotates on its axis, we see different parts of the sky throughout the night.

Magnitude
An object's magnitude tells you how bright it appears from Earth, represented on a numbered scale. The lower the number, the brighter the object. A magnitude of -1.0 is brighter than +2.0.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongation and as morning stars during western elongation.

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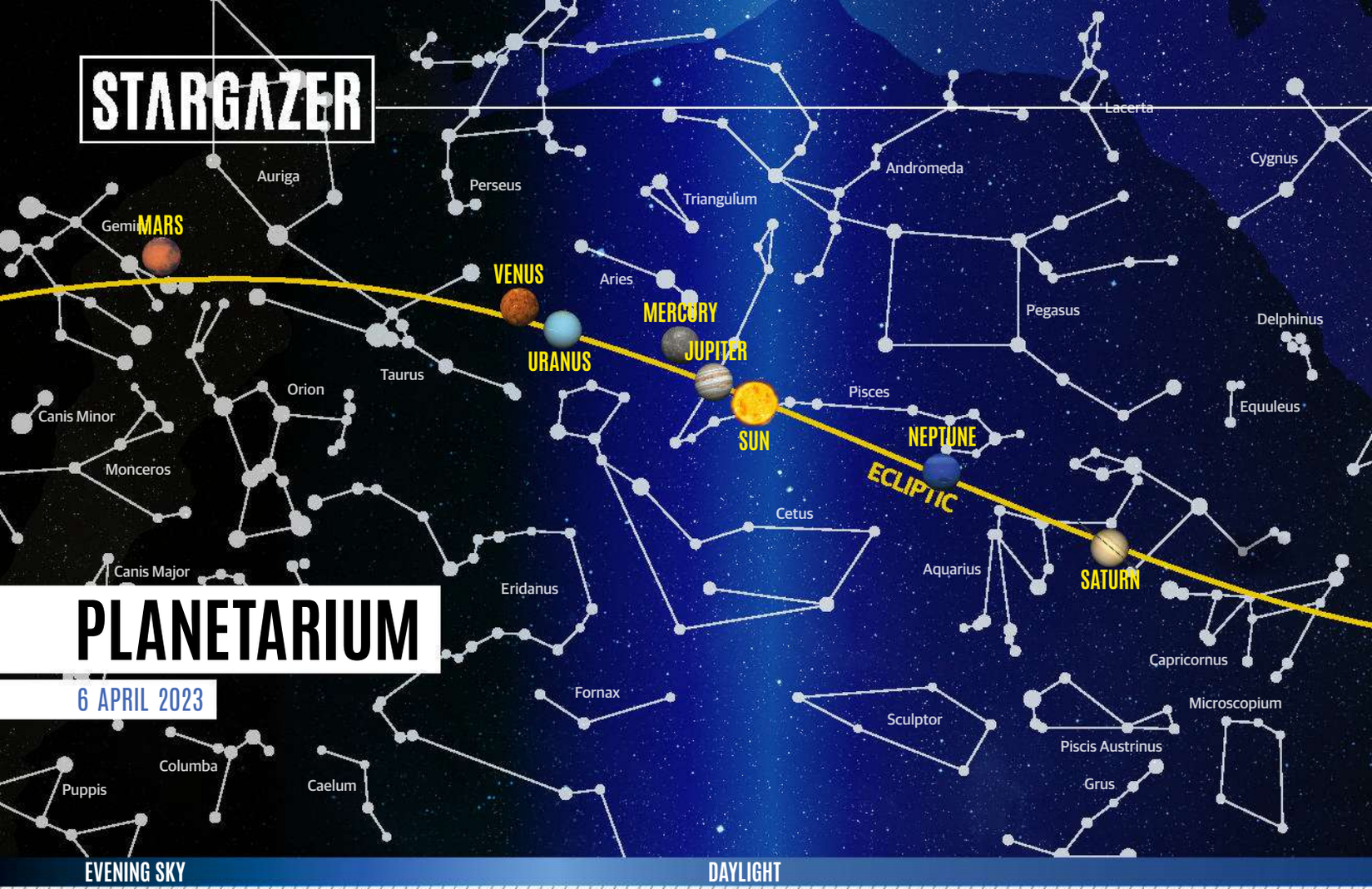


PLANETARIUM

6 APRIL 2023

EVENING SKY DAYLIGHT

MOON CALENDAR

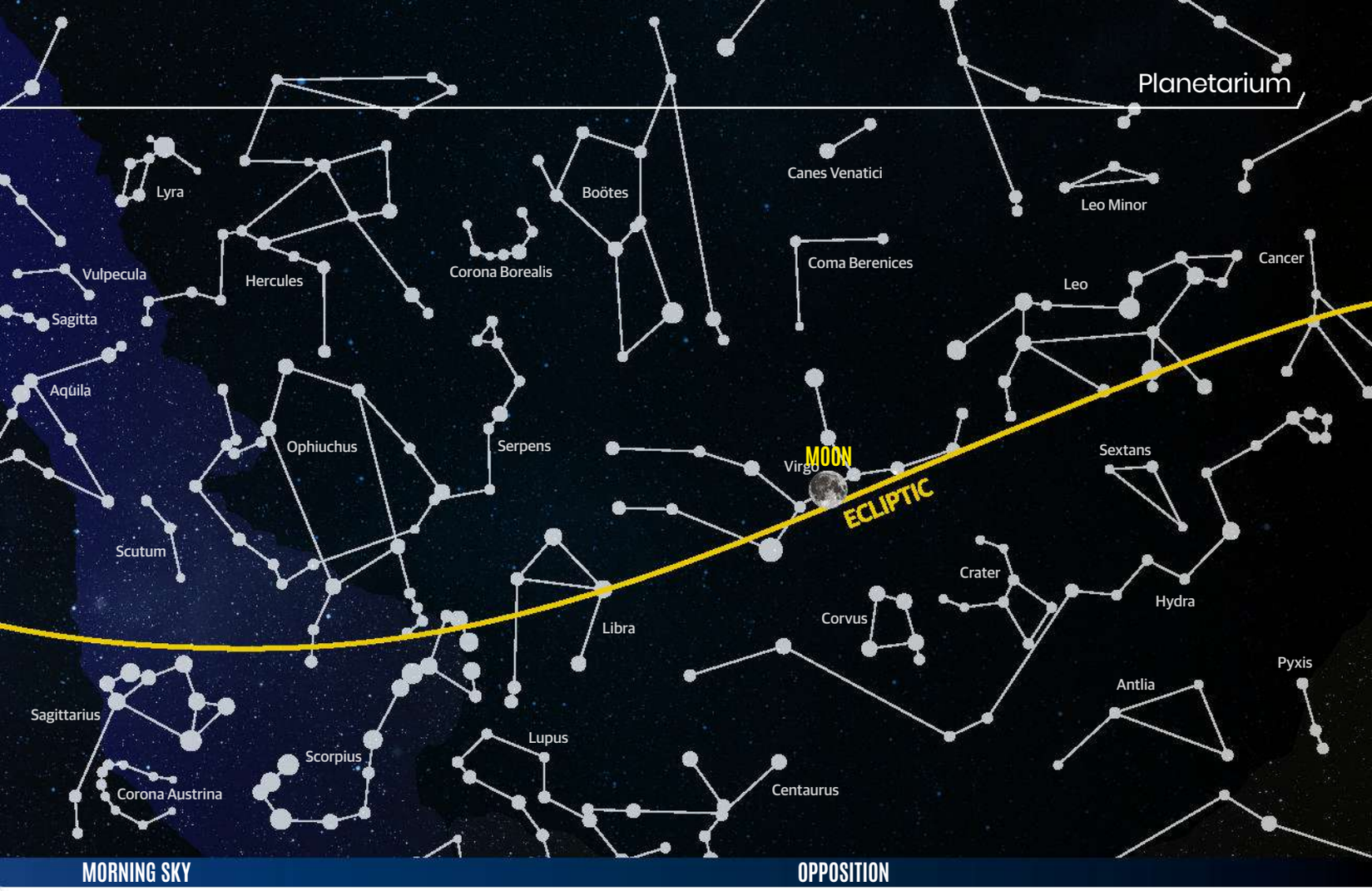
* The Moon does not pass the meridian on 4 April

23 MAR 4.5% 06:45 20:52	24 MAR 10.4% 07:00 22:15	25 MAR 18.1% 07:17 23:37	26 MAR 27.0% 08:40 --:--			
27 MAR 36.7% 01:54 09:10	28 MAR 46.7% 03:02 09:50	29 MAR FQ 56.6% 03:59 10:42	30 MAR 66.1% 04:41 11:45	31 MAR 75.0% 05:12 12:54	1 APR 82.9% 05:35 14:07	2 APR 89.6% 05:53 15:20
3 APR 94.9% 06:06 16:32	4 APR --.-*% 06:18 17:45	5 APR 98.4% 06:29 18:59	6 APR FM 99.9% 06:40 20:15	7 APR 99.3% 06:53 21:33	8 APR 96.3% 07:07 22:56	9 APR 90.9% 07:27 --:--
10 APR 83.5% 00:19 07:54	11 APR 74.1% 01:40 08:33	12 APR 63.3% 02:51 09:30	13 APR TQ 51.6% 03:45 10:43	14 APR 39.6% 04:23 12:09	15 APR 28.2% 04:49 13:39	16 APR 18.1% 05:09 15:08
17 APR 9.8% 05:24 16:34	18 APR 3.9% 05:38 17:59	19 APR 0.6% 05:50 19:23	20 APR NM 0.1% 06:04 20:47			

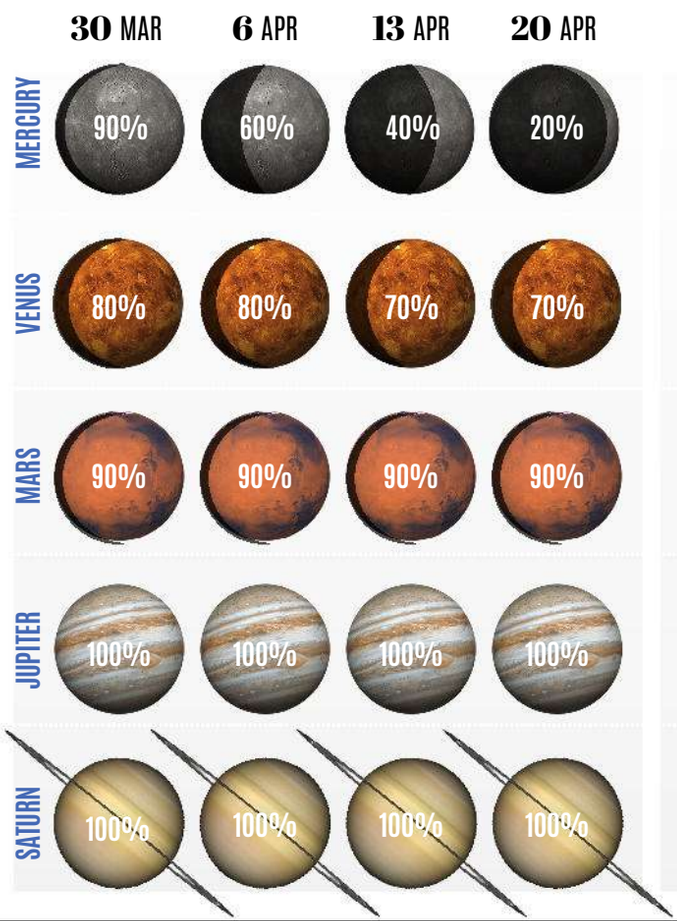
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

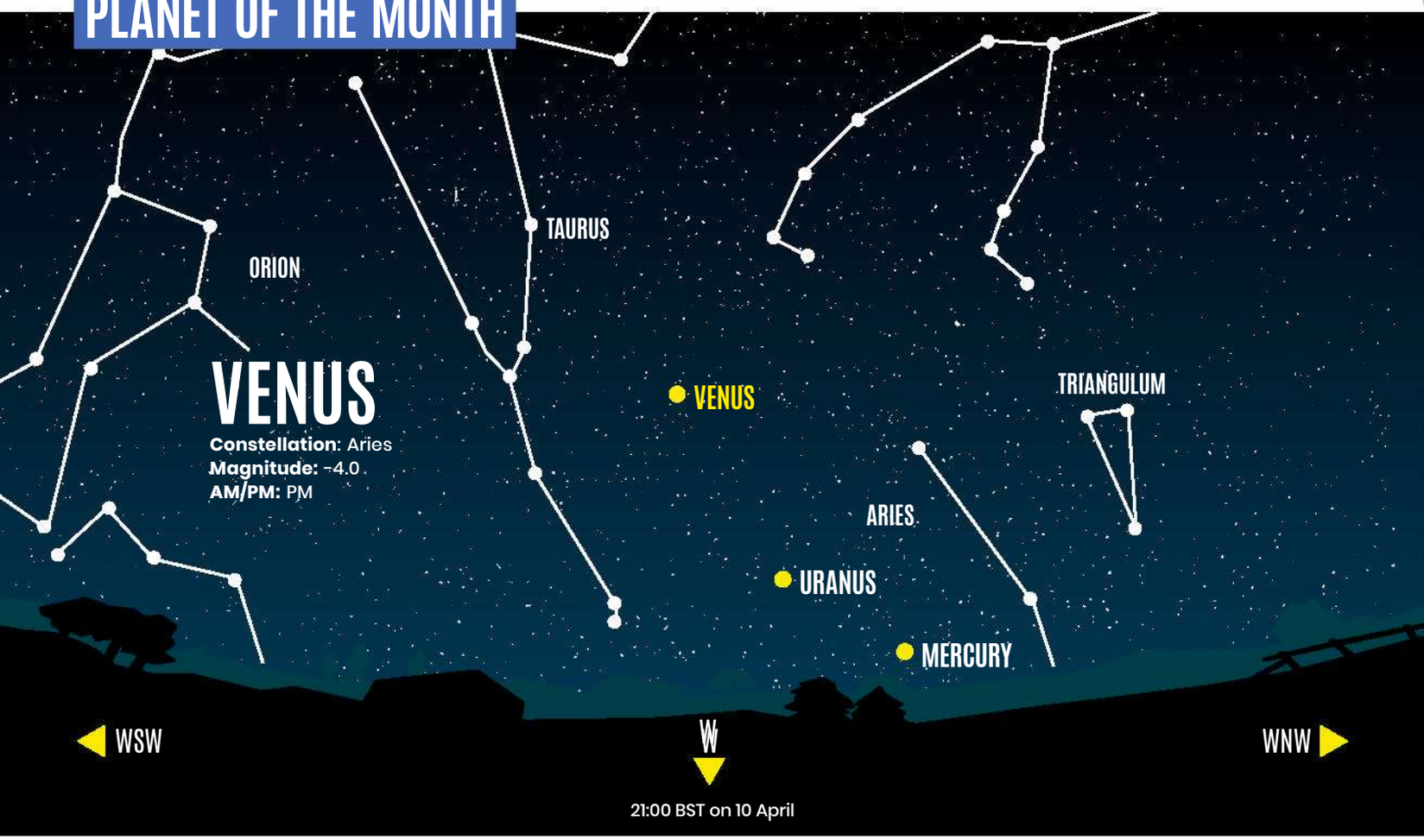
All rise and set times are given in GMT/BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
23 MAR	00h 28m 03s	+02° 14' 42"	Cetus	-1.7	06:13	18:34
30 MAR	01h 24m27s	+09° 40' 42"	Pisces	-1.2	06:59	20:37
6 APR	02h 07m 20s	+15° 03' 50"	Aries	-0.7	06:45	21:25
13 APR	02h 36m 38s	+18° 20' 58"	Aries	+0.3	06:27	21:51
20 APR	02h 47m 47s	+19° 08' 40"	Pisces	+2.0	06:06	21:44
23 MAR	02h 22m28s	+14° 42' 21"	Aries	-4.0	06:57	21:35
30 MAR	02h 55m 03s	+17° 38' 00"	Aries	-4.0	07:44	22:57
6 APR	03h 28m 17s	+20° 12' 39"	Aries	-4.0	07:33	23:20
13 APR	04h 02m 09s	+22° 22' 39"	Taurus	-4.1	07:24	23:41
20 APR	04h 36m 32s	+24° 04' 51"	Taurus	-4.1	07:18	00:00
23 MAR	05h 55m 23s	+25° 35' 08"	Taurus	+0.8	09:16	02:26
30 MAR	06h 10m 32s	+25° 29' 35"	Gemini	+1.0	10:04	03:12
6 APR	06h 26m 08s	+25° 18' 27"	Gemini	+1.1	09:53	02:59
13 APR	06h 42m 07s	+25° 01' 18"	Gemini	+1.1	09:44	02:45
20 APR	06h 58m 22s	+24° 37' 50"	Gemini	+1.2	09:35	02:31
23 MAR	01h 03m 54s	+05° 38' 16"	Pisces	-2.0	06:29	19:33
30 MAR	01h 10m 07s	+06° 16' 54"	Pisces	-2.0	07:05	20:15
6 APR	01h 16m 23s	+06° 55' 21"	Pisces	-2.0	06:40	19:57
13 APR	01h 22m 42s	+07° 33' 25"	Pisces	-2.0	06:15	19:39
20 APR	01h 29m 01s	+08° 10' 56"	Pisces	-2.0	05:51	19:22
23 MAR	22h 16m 11s	-12° 08' 56"	Aquarius	+1.0	05:14	15:15
30 MAR	22h 19m 03s	-11° 53' 41"	Aquarius	+1.0	05:48	15:52
6 APR	22h 21m 47s	-11° 39' 14"	Aquarius	+1.0	05:22	15:28
13 APR	22h 24m 21s	-11° 25' 43"	Aquarius	+1.0	04:56	15:04
20 APR	22h 29m 45s	-10° 57' 41"	Aquarius	+1.0	03:52	14:06

THIS MONTH'S PLANETS

Easter brings a feast of planets in the evening sky

PLANET OF THE MONTH

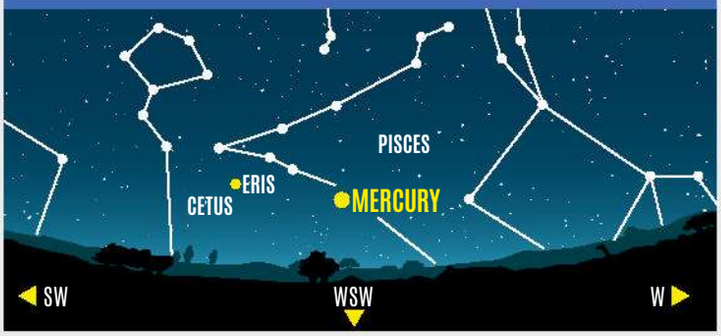


Venus will be strikingly bright in the sky through March and into April, and there will be so much going on around it. Venus is the second-closest planet to the Sun and the closest planet in the Solar System to Earth. Venus is often referred to as 'Earth's twin', but although Venus is roughly the same size as Earth, that's where the similarities end. Whereas Earth is a lush green world with a breathable atmosphere, liquid water on its surface and countless species of life, Venus is a hellish world with a thick, curdled atmosphere of poisonous carbon dioxide, acid droplets in its clouds and pressures so crushing on its surface that nothing could live there. This month Venus will be visible as a metallic spark of light embedded in the marmalade-hued twilight so bright that it will draw your eyes away from everything else around it.

At the start of our observing period Venus will be visible high in the west as soon as the sky begins to darken after sunset, with fainter Jupiter shining to its lower right. Venus will set three hours after the Sun, giving observers plenty of time to enjoy seeing it shining in the dusk. On the evening of 23 March, a lovely thin crescent Moon will be shining close to Venus, to its lower right, and the following evening that Moon will have moved past Venus to shine to its upper left. This will be a very striking sight to the naked eye and a lovely sight through binoculars. By 1 April Venus will be setting three-and-a-half hours after the Sun, and will have moved into the constellation of Taurus. It will be very close to the planet Uranus, although you'll need binoculars or a telescope to see that.

Between 10 and 12 April, Venus will pass between Taurus' famous pair of star clusters, the Hyades and Pleiades. On those evenings, scanning the sky around Venus through binoculars will be a wonderful treat, and even the camera on your phone should give great photos. By 20 April Venus will be setting four hours after the Sun and will look as bright and impressive as possible. Even people who aren't looking for it will be amazed by how bright it is, blazing in the twilight sky like a lantern or the lights of an approaching plane. If you have binoculars or a telescope, swing them towards Venus and you will be stunned by how spectacular it looks, like a finely cut gem sparkling and flashing against the darkening sky.

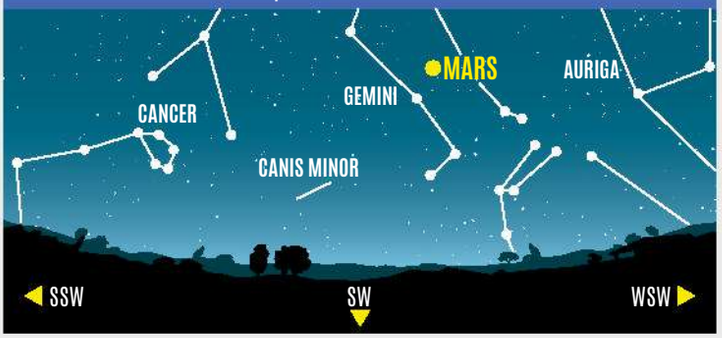
MERCURY 18:00 BST on 27 March



Constellation: Pisces **Magnitude:** -0.2 **AM/PM:** PM

Mercury will be low in the west after sunset, to the lower right of Jupiter. Setting just half an hour after the Sun, you might need binoculars to pick it out from the bright sky. Mercury will pull itself away from the sunset glow and up towards Jupiter, which it will pass very close to after dark on the evening of 27 March.

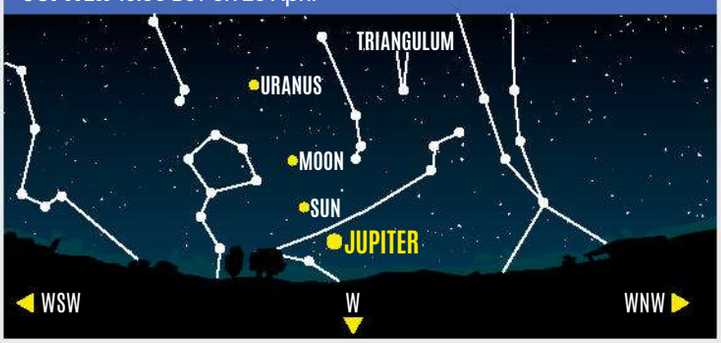
MARS 16:00 BST on 20 April



Constellation: Taurus and Gemini **Magnitude:** +0.8 **AM/PM:** PM

Although rather overshadowed by its neighbours, Mars will still be easy to see with the naked eye, looking like a bright-orange star almost directly above Orion. As the end of March approaches, Mars will be visible high in the southwest as soon as the sky begins to get dark, and won't set until the early hours of the following morning.

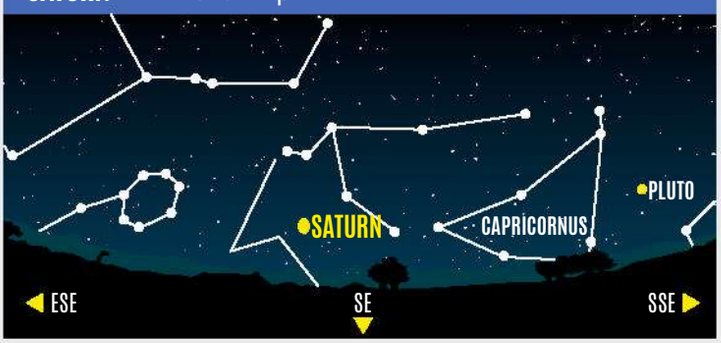
JUPITER 19:00 BST on 20 April



Constellation: Pisces **Magnitude:** -21 **AM/PM:** PM

At the start of our observing period Jupiter will be visible low in the southwest as twilight deepens, to the lower right of Venus, but it will lose height each evening as fainter Mercury drifts up towards it. On the evening of 27 March the two planets will shine side by side, just half a degree separating them, after which they will drift apart.

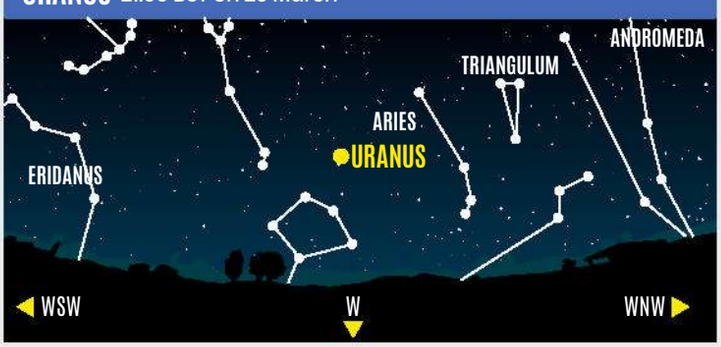
SATURN 07:00 BST on 1 April



Constellation: Aquarius **Magnitude:** +0.9 **AM/PM:** AM

Saturn, famous for its beautiful system of icy rings, will be a morning object at the start of our observing period, a yellow-white 'star' shining very low before sunrise, but as it will be rising barely 20 minutes before the Sun, finding it will be very challenging indeed. However, as the days pass Saturn's visibility will improve.

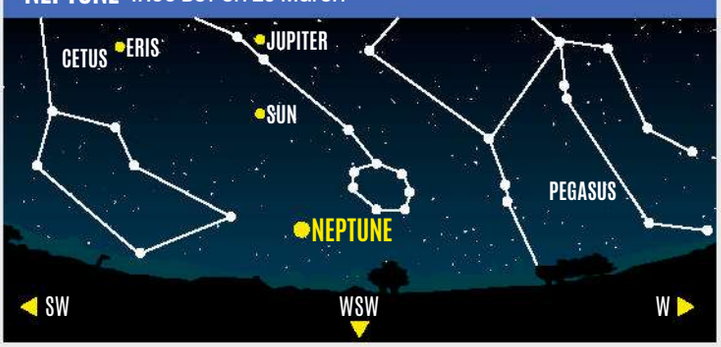
URANUS 21:00 BST on 29 March



Constellation: Aries **Magnitude:** +5.8 **AM/PM:** PM

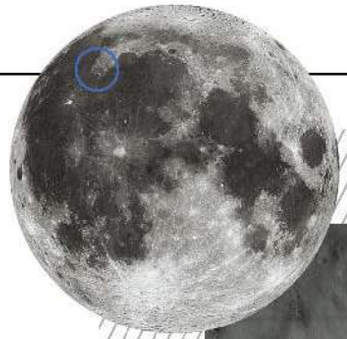
At the start of our observing period Uranus will be setting four hours after the Sun, positioned at the top of a long, steeply angled line of worlds stretched out across the western sky. Brilliant Venus will blaze to its lower right, Jupiter will shine to Venus' lower right and finally Mercury will be visible just above the horizon to Jupiter's lower right.

NEPTUNE 17:00 BST on 29 March



Constellation: Pisces **Magnitude:** +8.0 **AM/PM:** AM

This month Neptune will be a morning object, but as it will rise at the same time as the Sun it will not be visible. By the end of our observing period Neptune will be rising half an hour or so before the Sun, but that faint magnitude means it will be extremely hard to pick out of the brightening predawn sky.



MOON TOUR

MAIRAN

Overshadowed by its more famous neighbour Plato, Mairan is well worth a look on a clear night

There are a lot of craters on the Moon that would be more famous and better appreciated if they weren't so close to other features that were bigger, more prominent or just better looking. If you scan the lunar landscape around 'celebrity' craters like Copernicus and Ptolemaeus, you'll find lots of smaller craters that would be very popular targets for lunar observers if only they weren't so close to those beasts. Likewise, in the low-lying areas on either side of the curved dinosaur spine of the jagged Montes Apenninus, you'll find lots of smaller craters, hills and rilles worth looking at, but with their peaks jutting out of the surface so magnificently, nothing in their shadow gets a look in.

The same is true of this month's destination on our ongoing Moon tour. Look up towards the 'top' of the Moon at any phase past first quarter and you'll see the dark oval of Plato, a crater with a floor as smooth as marble – or so it appears under low magnifications. To Plato's left, or to its west, you'll see the equally famous semicircular bay of Sinus Iridum that looks like someone has taken a bite out of the lunar crust up there on the northern shore of Mare Imbrium. Both of those features are spectacular sights in a telescope, but if you can tear your eyes away from them and let them drift a little further west you'll find a small crater blasted out of the light-coloured rocky peninsula that leads away from Sinus Iridium, to the south of Sinus Roris. This crater is Mairan.

Physically, Mairan is a 39-kilometre (24-mile) wide, four-kilometre (2.5-mile) deep hole, or pit, blasted out of the Moon unknown millennia ago. In common with countless hundreds of thousands of other craters its size, Mairan has steep, terraced walls that are slumped in places, leading down to a relatively flat floor with a scattering of smaller craters sprayed across it. Mairan has many small secondary impact craters spattered around it, none of them particularly noteworthy.

So, when can you see this crater for yourself? At the start of our observing period Mairan isn't visible, as it will be deep in the darkest depths of lunar night. It won't be until 2 April that the crater begins to return to view, as the terminator – the line between lunar night and day – sweeps over it and the first slanting rays of sunlight fall on its western rim. Between 14 and 15 April the crater will be a very attractive object in telescope eyepieces as its close proximity to the terminator will mean its walls, floor and rim are all illuminated from the side, their shadows making the crater look very prominent. When the Moon reaches full phase on 6 April, Mairan will fade into the background; with the Sun overhead it will look less like a hole and more like a light circle with a darker floor through telescopes.

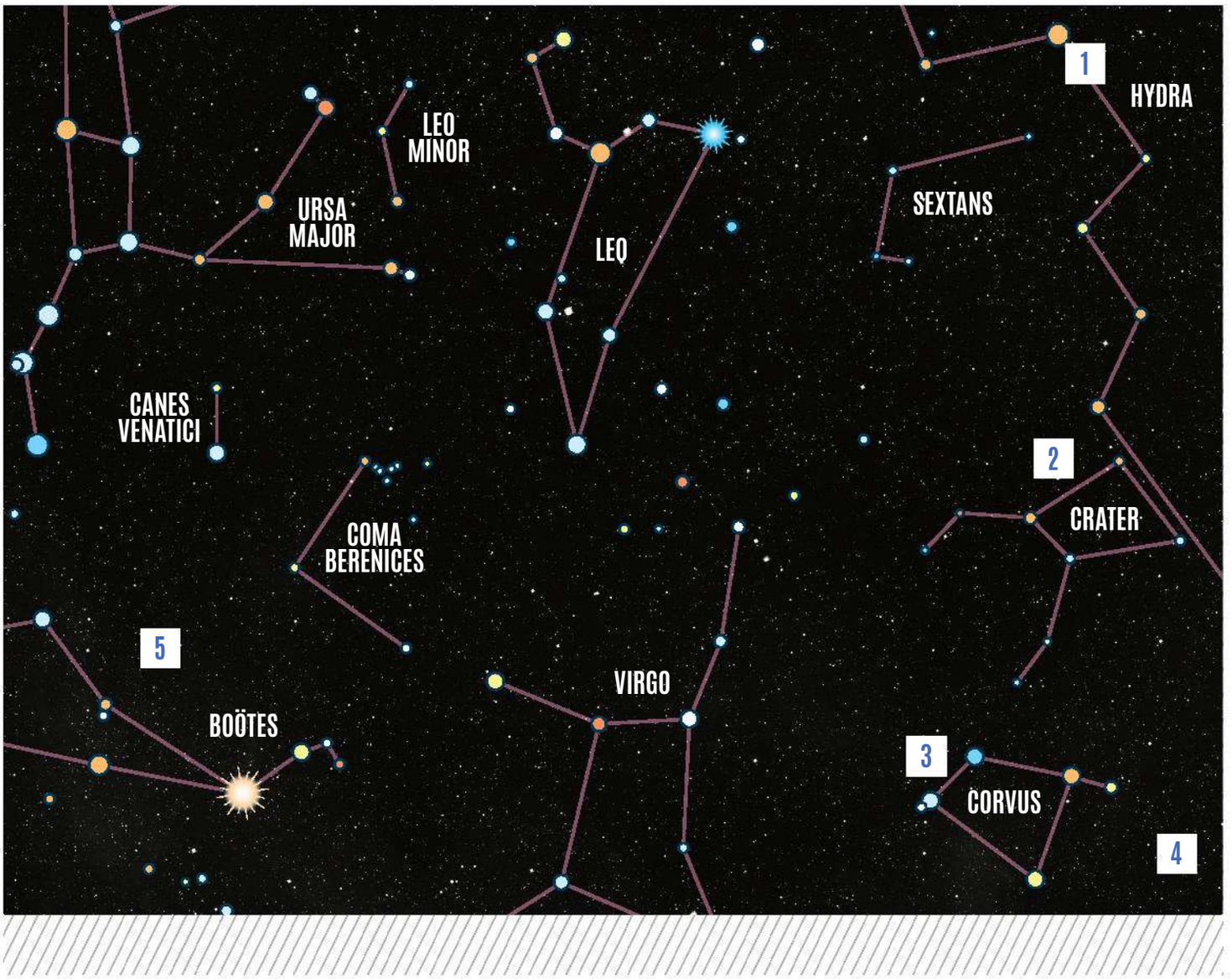
On 16 April the terminator will sweep over the crater again, this time from the east, and it will be plunged into darkness once more. We won't be able to see it again until long after the end of our observing period.

If Mairan was on its own, somewhere further south out on the dark rolling plain of Mare Imbrium, for instance, it would attract a lot more attention. But embedded in that peninsula it's usually overlooked by observers impatient to swing their telescopes towards Plato or Sinus Iridum, but you can't really blame them for that. However, the crew of Apollo 15 obviously thought the crater was worthy of some attention, because as they flew over it in 1971 they took several photos of it from lunar orbit. More recently, NASA's Lunar Reconnaissance Orbiter has taken much higher resolution images of the crater showing details on its inner walls, including boulders and landslides.

© NASA

TOP TIP!

Be sure to look for Mairan when it's near the terminator, as its features and structure will stand out more clearly.



NAKED EYE AND BINOCULAR TARGETS

Lone stars and globular clusters are among the treats on view in spring

1 Alphard
This star's name means 'the solitary one'. Alphard is aptly named, as it's the only bright star in this region of sky. Hydra (the Water Snake), the constellation that this magnitude +2.0 star occupies, stretches across the sky. To the naked eye and binoculars, Alphard has a warm orange colour.

2 Crater
This constellation is said to represent a cup of water brought to the god Apollo by a crow. +3.56 Delta Crateris and +4.07 Alpha Crateris are the constellation's two brightest stars, which are easily detected with 10x50 binoculars.

3 Corvus
Corvus represents the crow sent to collect water by Apollo, but brought him a snake instead and was thrown into the heavens. While you can't see them, at least three of Corvus' star systems have exoplanets. Corvus also has an ageing blue giant star, Gamma Corvi, which has a magnitude of +2.59.

4 Messier 68
Globular star cluster Messier 68 has a dense core and is 33,000 light years away. Under good observing conditions, this star cluster appears to have a fuzzy halo that fades to the edges. This tight collection of stars is visible through 7x50 binoculars.

5 Messier 3
One of the brightest clusters in the Northern Hemisphere, Messier 3 is easily visible in binoculars as a hazy ball of stars. The cluster is seen as one of the finest northern sights, with its collection of 274 known variable stars making it visible to even the slightest of optical aids.

3 Markarian's Chain

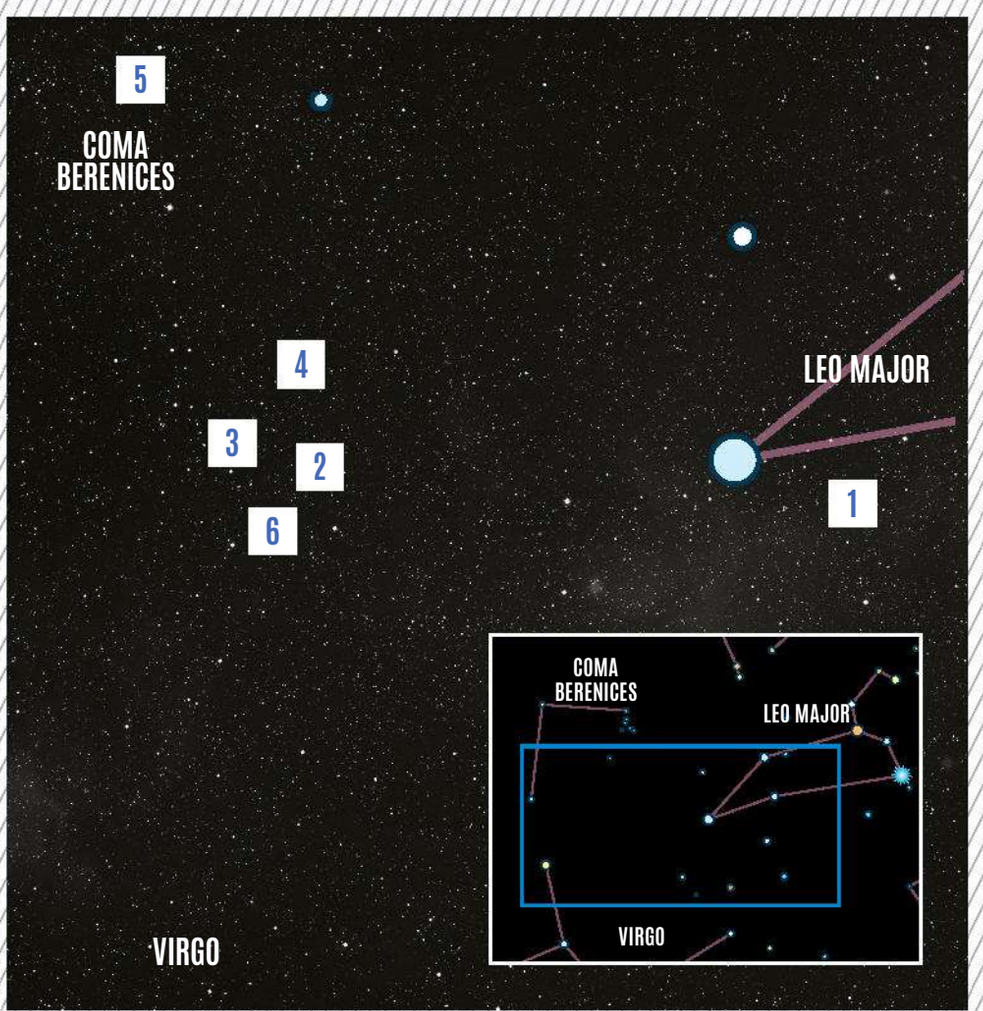
DEEP SKY CHALLENGE

THE 'REALM OF THE GALAXIES'

Evenings reveal a gaggle of must-see structures when we look out into deep space in the direction of one of the most well-known constellations

The region of sky around Leo, Coma Berenices and Virgo is known as the 'Realm of the Galaxies', and this is a perfect time of year to go hunting for those faint, fuzzy and very distant objects. Galaxies come in all shapes, sizes and distances; this means they can seem larger and brighter, or smaller and fainter, depending on their individual attributes. They can also come in groups. This can be a line-of-sight effect or it can be the result of gravitational interactions between individual galaxies. Some larger, brighter galaxies can be spotted in binoculars, but most require at least a small telescope – the larger the aperture, the more you'll see and the brighter objects will appear. Here are just a few of the most interesting objects for the deep-sky observer.

4 Messier 100



1 The Leo Triplet

Messier 65, Messier 66 and NGC 3628 make a lovely sight in just about any size of telescope. Since they're tightly knitted together, these three spiral galaxies are visible in the same field of view.

2 Messier 86

This is an unusual elliptical galaxy found in the heart of the Virgo Cluster. It is associated with a similar elliptical galaxy, Messier 84. Given its +8.9 magnitude, you'll need a telescope with a small or medium aperture to show up an oval-shaped patch.

3 Markarian's Chain

Containing Messiers 84 and 86, this is a long, curved line of galaxies that form part of the Virgo Cluster. Small telescopes will pick out the length of the chain, but you'll need a telescope with a large aperture to see the much fainter members.

4 Messier 100

Spiral galaxy Messier 100 is one of the largest and brightest objects in the Virgo Cluster, shining at magnitude +9.3. Its 'grand design' structure is difficult to pick out – you'll need a telescope with an eight-inch aperture and good observing conditions.

5 The Black Eye Galaxy

Messier 64 has a dark dust lane near its nucleus that gives rise to its name – the Black Eye Galaxy. A six-inch telescope will reveal the galaxy as a smooth oval, with its dark band becoming more obvious from a dark-sky site.

6 Messier 87

This supergiant elliptical galaxy in the Virgo Cluster is one of the most massive objects in our local universe. At magnitude +8.6, Messier 87 is readily observed using a small telescope, but you'll need the art of astrophotography to capture this galaxy's jet.

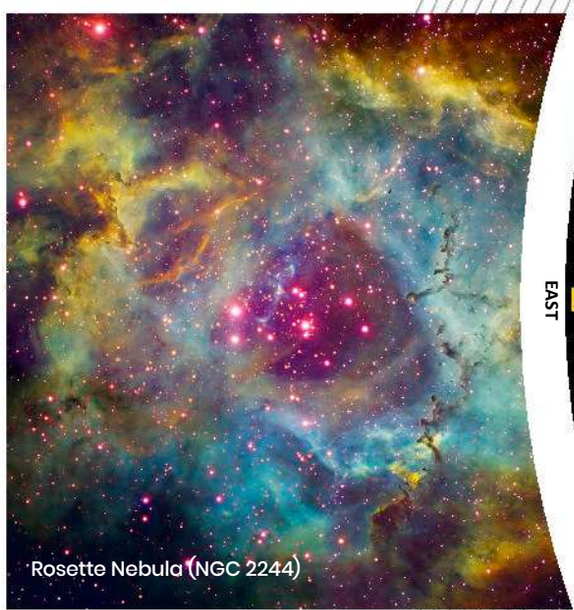
© ESO; Source: Wikipedia Commons/ Nielander

NORTHERN HEMISPHERE

Some bright stars of winter still linger after sunset

The bright yellow-white star Capella of Auriga (the Charioteer) sits low in the northwestern sky this month, a striking sight at magnitude +0.08 alongside easy-to-locate Gemini's (the Twins) Castor and Pollux. Ursa Major's 'Big Dipper' is the easiest asterism to find as soon as darkness falls, making it easy to use its pointer stars to find Polaris. Follow the pointers in the other direction and you'll find bright-white star Regulus in Leo (the Lion), and trace your finger along the bowl and you'll find yourself led to brilliant yellow-orange star Arcturus in the constellation of Boötes (the Herdsman). Nearby, just northeast of Arcturus, you'll be greeted by the unmistakable semi-circle of the Northern Crown, Corona Borealis.

Wishing Well Cluster (NGC 3532)


Rosette Nebula (NGC 2244)

Markarian's Chain, forming part of the Virgo Cluster

Using the sky chart

This chart is for use at 22:00 mid-month and is set for 52 degrees latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

Magnitudes

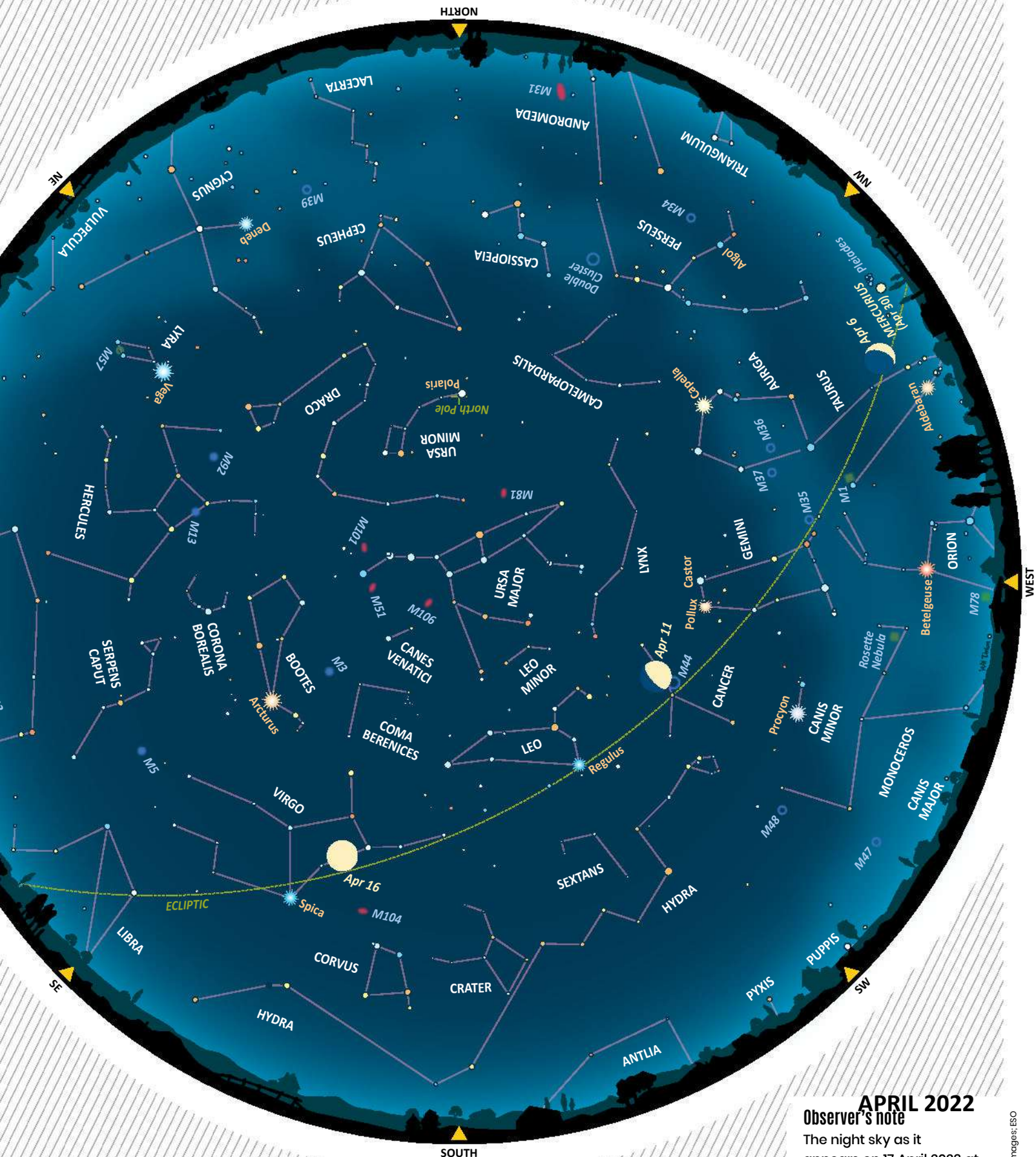
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to +0.5
- +0.5 to +1.0
- +1.0 to +1.5
- +1.5 to +2.0
- +2.0 to +2.5
- +2.5 to +3.0
- +3.0 to +3.5
- +3.5 to +4.0
- +4.0 to +4.5
- Fainter
- Variable star

Spectral types

- O–B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



APRIL 2022

Observer's note

The night sky as it appears on 17 April 2023 at approximately 22:00 (BST)

© Getty Images; ESO

REVIEW

SONY A6600

Does Sony's latest APS-C camera live up to the high standard set by its predecessor?

Reviewed by Kimberely Lane

The latest release in Sony's Alpha range of APS-C cameras is the A6600. Released just months after its predecessor, the revolutionary A6500, you might wonder why Sony released two cameras in the same range so close together. You would expect the A6600 to have some fantastic new features that Sony just couldn't wait to share. The Sony A6600 utilises professional features in an APS-C body. It has the same class-leading features we've come to expect from Sony. It's robust, solidly built and has a full-frame feel.

But does the A6600 live up to the high standard set by its predecessor? The Sony A6600 is powered by the high-performance Z-series battery, a first for APS-C cameras. The upgraded battery has over twice the capacity of

CAMERA ADVICE

Cost: £1,249 / $1,349.95

From: Sony

System: Mirrorless

Sensor: APS-C

ISO range: 100 to 3,200

Burst shooting: 11 frames per second

AF: 425 phase-detect autofocus points

Video: 4K/30p video recording

Storage: UHS-I SD

Screen: Tilting three-inch touchscreen

Dimensions: 120 by 66.9 by 69.3 millimetres (4.72 by 2.63 by 2.73 inches)

Weight: 503 grams

The camera is bulkier, but feels good to grip

The A6600 features a useful tilting screen

the previous FW50 battery. To accommodate the larger Z battery, Sony has made the grip on the A6600 much bigger than any of its previous models – holding this camera in your hands is an absolute joy. The biggest improvement in design is the bigger grip, allowing comfortable handling and greater stability.

The design looks the same overall until you get it in your hands. We compared it directly to the A6300, and the difference is night and day. Alongside being easier to grip, it feels more robust and rugged than many of the previous models in this range. There are three custom buttons, and each button on the back is more pronounced, making them easier to find, especially in the dark, and press. The tilting screen is excellent for vlogging or taking selfies. There's no denying this is a great camera, but there are a few design niggles that Sony could've easily solved – particularly given how expensive this camera is. In our opinion, the video record button is still in a strange place. The front grip is just begging for a dial to make changing settings on the go that much easier.

The increase in grip size would have allowed the addition of a second card slot, or alternatively an upgrade to the existing card slot – making it compatible with faster cards would have been advantageous. There's no USB-C port, but it does have a headphone jack, allowing you to listen to audio during recording – a valuable feature for video. Sony also could have included a higher resolution viewfinder. One strange design decision is the removal of the pop-up flash, which was replaced with literally nothing. We can't fathom why Sony removed it. There's a hot shoe to attach an external flash, but even the cheapest one will add cost.

While this camera isn't revolutionary, there are still areas where it outclasses the competition, like the autofocus and tracking, where Sony is years ahead. Sony's real-time tracking is lightning-fast and highly accurate. It identifies the focal point and seamlessly switches between subjects. To put the eye tracking and autofocus through its paces, we used the 'black cat test.' Black cats are notoriously difficult to photograph, as most cameras don't pick up the cat's face in the frame. Overall, the autofocus feature of the A6600 did a good job of tracking the eyes, provided the lighting was good and the subject was looking at or facing the camera. Once the subject looked away, it didn't switch to face tracking; this is a feature we'd love to see on this camera. Once the subject looked back towards the camera, it quickly recognised and started tracking the eyes again. There were instances when it struggled to detect the eyes, though we were shooting in unfavourable conditions – inside on a dull day.

The camera selected an ISO of 6400 in this indoor space, giving some minor noise in the images, but nothing that can't be fixed in post-processing. The images were incredibly sharp, and when it did get the autofocus correct, it was spot on. This camera is terrific

"It has the same class-leading features we've come to expect from Sony. It's robust, solidly built and has a full-frame feel"

BEST FOR...

- £ LARGE BUDGETS
- CASUAL ASTROPHOTOGRAPHERS
- WIDE-ANGLE ASTROPHOTOGRAPHY
- SKYSCAPES
- LOW LIGHT
- VIDEO

The build quality is excellent, and the buttons are more pronounced

for astrophotography using longer shutter speeds on a tripod. You can afford to ramp the ISO right up before you start to see any noise. Sony cameras are so good in low light that you can get away with lower ISO levels when paired with the right lens and still get incredible detail.

In terms of video, this camera is good, but it's not a camera that's designed with videographers in mind. That said, it performs well enough for decent vlogging and as a general video camera for documentary or casual travel videos. Although it has built-in cinematic modes, it doesn't have the fastest video rates. The A6600 is one of the few crop-sensor cameras with in-body stabilisation – the other being the A6500. This is a great feature for an APS-C camera, but there haven't been any improvements to the stabilisation since the previous model, and it isn't anything revolutionary. That said, the A6600 is still king when it comes to in-body stabilisation and autofocus, making it better than most crop-sensor options from many other brands.

We'd have loved for Sony to improve the sensor in this camera. The A6600 isn't an inexpensive camera, so why does it still have the same sensor as its predecessor? There's nothing necessarily wrong with the sensor; it delivers rich colours, natural skin tones and crisp details. A new processor helps the camera deliver better quality images, but in our opinion Sony should have upgraded the sensor in this model to 26 megapixels. If it does bring out another camera in this range, this would be a welcome addition, especially if it's going to have a similar price point.

Even with its drawbacks, the tracking and autofocus on this camera are untouchable. That said, this is becoming the norm with Sony cameras. Aside from that, not many features differ between all Sony camera models. You could argue that once you've used one Sony camera, you've used them all. Upon its release, there was a lot of negativity surrounding this camera. Everyone loved the A6500 as there was nothing else like it at the time. The only major improvements are the real-time tracking autofocus, in-body stabilisation and a bigger battery. Sadly, due to the lack of innovation, the A6600 didn't come with as much of a wow factor as Sony would have liked.

One big issue with this camera is the price. As it's nothing groundbreaking, you must wonder whether it's worth the huge price tag for just the body alone. Would you be better off paying a little bit more and purchasing an older full-frame camera? It may not be worth upgrading from your current camera, but with that said, if you are looking for a fantastic APS-C camera with in-body stabilisation, flawless tracking and have the budget for it, the A6600 is a great option. However, you could get the same specs for much cheaper – consider the A6400 or the A6100 for a better bang for your buck.

"It feels more robust and rugged than many of the previous models"

There's a single UHS-I SD slot for storage

The autofocus, stabilisation and tracking are all great features

FOR

- In-body image stabilisation
- Sony Z-series battery
- Sony's class-leading real-time tracking

AGAINST

- Nothing revolutionary
- Similarly priced to full-frame cameras
- Same sensor as its predecessor

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IN THE SHOPS

The best telescopes for viewing Solar System planets

"It's a simple telescope designed for seeing the Moon, planets and bright deep-sky objects"

Best for beginners

Celestron Inspire 100AZ

Cost: £259 / $359.95
From: Celestron

1 Beginners who want to explore the world of astronomy should consider starting with a traditional refractor telescope like the Inspire 100AZ, which is especially adept at viewing planets. It's a simple telescope designed for seeing the Moon, planets and bright deep-sky objects, and it doesn't feature any fancy Go-To motors or app integration, but it does come with the basic edition of Celestron's Starry Night software to help you learn about the night sky. We were able to see the Andromeda Galaxy (Messier 31) and some bright star clusters, but the aperture doesn't let in as much light for anything beyond that. However, it resolves Solar System targets well.

Best for imaging

Celestron CPC Deluxe 1100 HD

Cost: £5,499 / $5,099
From: Celestron

2 Planetary imaging is an addictive hobby, and fortunately you can get started on any telescope with a mount that tracks the sky. But if you plan to get serious, a large-aperture instrument is a must. It provides greater resolution, allowing more details to be recorded by the imaging sensor. The CPC Deluxe 1100 HD features a high-performance main mirror, capable of resolving the surfaces of the most remote planets. On targets such as Venus and Jupiter it sees remarkable detail, and the skilled observer can even pick out landmarks on Mars without too much difficulty. The CPC mount is robust and dependable, offering excellent tracking for lengthy imaging sessions.

Best for versatility

Sky-Watcher Explorer-130 EQ2

Cost: £199 / $236
From: Sky-Watcher

3 The Sky-Watcher Explorer-130 EQ2 is an excellent choice for those serious about taking the first steps into the world of astronomy. Unlike other models at a similar price point, this telescope ships with an equatorial mount. This can take a bit of getting used to, but once it's aligned with Earth's axis, it makes it simple to track objects in the sky once you've found them as Earth rotates. It has a good-sized aperture, which means you will be able to explore some deep-sky objects, albeit only the brightest ones. We could easily get sharp views of Jupiter, its rings and moons, and Saturn's rings looked impressive using the included 2x Barlow lens.

Best Go-To functionality

Celestron Astro Fi 102

Cost: £415.99 / $529.95
From: Celestron

4 The Astro Fi 102 is an excellent choice for tech-savvy beginners who want to get closer to the planets. After the initial set up of the motorised mount, which can take a little time, it's a breeze to use alongside the SkyPortal app, downloadable for iOS and Android. The app, which we found to work seamlessly during our test of the Celestron Astro Fi 102, features approximately 100,000 celestial objects, which you can 'instruct' the instrument to slew to automatically. The views aren't breathtaking, as we would expect at this price point, but you will get good close-up views of the Moon, Saturn's rings, Mars and Jupiter, as well as Uranus and Neptune in the right conditions.

Best for overall value

Celestron Omni XLT AZ 102

Cost: £325 / $329.95
From: Celestron

5 The Omni XLT 102 is quite a unique offer, including a good telescope and mount combination. It's easy to set up and doesn't require any tools. The f/10 achromat gives fine views, and its focal length makes it a good match for some of the best planetary eyepieces. Only one is supplied, but with the addition of a 10mm and Barlow lens, you can achieve a magnification of 36x, 72x, 100x and 200x. At this top end, the Omni XLT 102 will show you some lovely details on our neighbouring planets. Being an equatorial mount, it requires some practice to set up and get to grips with, but once you're used to it, and the slow-motion controls, it offers easy one-handed tracking of the planets.

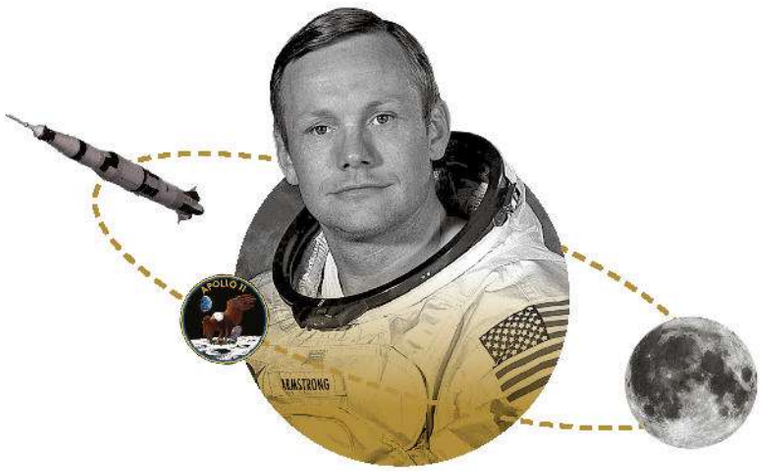
Best for precision

Sky-Watcher Skymax 180 PRO

Cost: £2,449 / $3,160
From: Sky-Watcher

6 The Skymax 180 PRO was purpose-built for Solar System exploration. Its high-resolution long focal length delivers performance akin to a much costlier large apochromatic refractor, providing flawless images of the planets rich in colourful details. It also has enough light grasp to bring many of the Solar System's moons into view. The single eyepiece won't make the most of this telescope's potential, so you'll need to invest a little extra, but even a comfortable 8mm or 10mm planetary eyepiece will be well tolerated by its formidable optics. For optimal accuracy, the Skymax 180 PRO is paired with an HEQ5 PRO equatorial mount, ideal for heavy payloads.

HEROES OF SPACE



NEIL ARMSTRONG

Armstrong's legacy as the first human on the Moon will forever be remembered

Born on his grandparents' farm near Wapakoneta, Ohio, on 5 August 1930, Neil Alden Armstrong developed an early interest in flying. He had his student pilot's licence at the age of 16, before he'd even passed his automobile driver's test. He received a scholarship from the US Navy after high school and studied aeronautical engineering at Purdue University, Indiana. Armstrong was later called up for active duty in the Korean War, flying 78 combat missions from 1950. In 1952 he joined the National Advisory Committee for Aeronautics (NACA), the successor of which would become the National Aeronautics and Space Administration (NASA). He transferred to NASA's Flight Research Center in California in the mid-1950s, piloting several experimental aircraft, including the 6,437 kilometre (4,000 mile) per hour X-15 rocket jet. In total he flew over 200 different types of aircraft.

In 1962 Armstrong was picked among NASA's second group of astronauts and began astronaut training in Houston, Texas. Armstrong went to space for the first time on the Gemini 8 mission, where he was the command pilot alongside fellow astronaut David Scott, which launched on 16 March 1966. He performed the first successful docking of two vehicles in space – his Gemini 8 spacecraft and an Agena target spacecraft. He was then selected as the spacecraft commander for Apollo 11, the first spacecraft to land on the Moon. Just after 20:00 UTC on 20 July 1969, Armstrong piloted the Lunar Module to the surface with fellow astronaut Buzz Aldrin alongside him, but the landing didn't go quite as smoothly as they'd hoped. He had to perform some last-second manoeuvres to set the spacecraft down as he searched for a suitable landing spot. He landed with just several seconds of fuel left to spare, a testament to his skilled piloting capabilities. Several hours later he left the lander and stepped onto the lunar surface, uttering the immortal line: "That's one small step for [a] man, one giant leap for mankind."

Armstrong held the position of deputy associate administrator for aeronautics for the Office of Advanced Research and Technology in the early 1970s, resigning in 1971 to become a professor of aerospace engineering at the University of Cincinnati until 1979. He lived on his farm in Cincinnati, Ohio, before passing away on 25 August 2012 at the age of 82.

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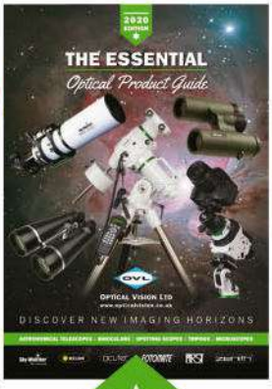

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